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Myopia

Prevalence and Progression

MYOPIA: PREVALENCE AND PROGRESSION

Working Group on Myopia Prevalence and Progression

Committee on Vision
Commission on Behavioral and
Social Sciences and Education
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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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Foreword

The Committee on Vision is a standing committee of the National Research Council's Commission on Behavioral and Social Sciences and Education. The committee provides analysis and advice on scientific issues and applied problems involving vision. It also attempts to stimulate the further development of visual science and to provide a forum in which basic and applied scientists, engineers, and clinicians can interact. Working groups of the committee study questions that may involve engineering and equipment, physiological and physical optics, neurophysiology, psychophysics, perception, environmental effects on vision, and treatment of visual disorders.

In order for the committee to perform its role effectively, it draws on experts from a wide range of scientific, engineering, and clinical disciplines. The members of this working group were chosen for their expertise in vision research, for their familiarity with epidemiological approaches to the study of myopia, and for their knowledge of present-day approaches to its assessment and treatment.

This report considers the issues surrounding the occurrence, progression, and predictability of myopia, with special emphasis on the 16-26-year-old population. The report is based on an analysis of findings in the available literature and represents in itself an important contribution to the literature base by virtue of the efforts of the working group to identify and review only the most pertinent published research in this area. The observations and recommendations arising from the efforts of this working group will undoubtedly be of considerable interest to vision scientists and clinicians alike.

Robert Sekuler, Past Chair
Committee on Vision

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Preface

At the request of the U.S. Air Force School of Aerospace Medicine, the Committee on Vision established the Working Group on Myopia Prevalence and Progression in 1984. The working group was asked to address three questions:

> What demographic and confounding variables must be evaluated in comparing older myopia prevalence data with current data?
>
> Are there variables by which changes in refractive error can be predicted for an individual?
>
> What agenda for future research would substantially increase our knowledge of myopia prevalence and progression?

Myopia is commonly known as nearsightedness. A nearsighted individual, or myope, sees near objects well but sees distant objects poorly. Prevalence estimates from the 1972 National Health and Nutrition Examination Survey of persons in the United States between the ages of 12 and 54 years indicate that 25 percent were myopic.

Individual differences are also known to occur in the progression of myopia. Ophthalmic clinicians widely acknowledge that once a youngster becomes myopic, he or she will most likely become more myopic, and this increase in myopia will stop or slow down sometime in the teenage years or later. There is, however, a great deal of individual variability in age at which progression ceases.

In order to answer the questions put by the U.S. Air Force School of Aerospace Medicine, the working group established as its goals:

- the specification of classification criteria for the estimation of myopia prevalence;
- the identification of some of the probable determinants of myopia prevalence;
- a consideration of some of the factors contributing to the etiology of myopia;
- the specification of the characteristics of myopia onset and its progression;
- a review of the refractive changes in myopia progression in children and young adults; and
- the creation of a selected bibliography on myopia prevalence and progression.

To accomplish these goals, the working group developed a research plan to review what is known about myopia. An extensive literature review was conducted. Over 500 articles were identified, the majority of which had been published in the last 40 years in English-language journals. A significant number of articles in nineteenth century periodicals were also identified. These articles were distributed to subgroups of the working group for

analysis. In addition to the literature search, staff identified a limited number of published research findings in languages other than English. This report builds on those analyses and the discussion that took place at the meetings of the working group over a two-year period.

In addition to the members of the working group, a number of people contributed in important ways to the success of the project. Carol Masters, Harvard School of Public Health, provided extensive consultation on issues related to prevalence of myopia and is responsible for much of the material presented in the review of the prevalence literature (Appendix B). The working group is particularly grateful for her assistance. Wayne Shebilske, the committee's study director through June 1985, planned the project and the initial phases of the research plan. Pamela Ebert Flattau, the committee's study director after July 1, 1985, provided important assistance in overseeing the effort and in preparing the working group's report. Colonel Thomas Tredici, Brooks Air Force Base, and Constance Atwell, National Eye Institute, provided valuable technical advice at the meetings of the working group.

Secretarial and administrative assistance were provided by Carol Metcalf and Gora P. Lerma, for which the working group is grateful. Christine L. McShane, editor of the Commission on Behavioral and Social Sciences and Education, helped improved the style and clarity of the report.

Anthony J. Adams, Chair
Working Group on Myopia
Prevalence and Progression

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Summary of Conclusions and Recommendations

In this report we analyze the findings of research published since the early 1800s on the progression and prevalence of myopia (nearsightedness). We show that, although problems arise from the use of the myopia literature, it is possible to draw certain inferences about changes in myopia in certain populations. One concern was whether there have been significant changes over time in the prevalence of myopia among young adults who are eligible for military academy training. Another involves the nature and progression of myopia among young adults. Although we encountered interpretation difficulties with many of the studies and reports we surveyed, we believe our conclusions are reasonable. Highlighted below are some of the most important points we make in our report, cross-referenced to the appropriate sections of the document (a glossary of technical terms appears in Appendix E):

- Studies of the prevalence of myopia during the past 100 years indicate no significant change in the distribution of refractive errors within the groups of Caucasian schoolchildren and college-age young adults. An exception to this finding is that high or severe myopia is less prevalent now at all ages (pp. 10-11, 48-50).
- Myopia can start and can increase after age 16, although it is less severe and appears limited to a smaller proportion of these individuals. The degree of myopic change or shift among young adults is apparently small enough to go undetected in cross-sectional studies of the general population (pp. 23-25, 72-73).
- From 1812 to the present, studies indicate that myopia is much more prevalent among college students and young adult males who enter military officer training than among other populations at similar ages (pp. 19-21, 74-78).
- Doing near work places one at risk for myopia. On the basis of all studies reviewed, we estimate that as many as 20 to 40 percent of low hyperopes (those who are slightly farsighted) and emmetropes (those without refractive error) who enter colleges and military academies or pursue occupations with extensive near work requirements are likely to become myopic before the age of 25. For populations in which selected college and special near work groups have been excluded, less than 10 percent of emmetropes and low hyperopes will develop myopia prior to becoming presbyopic (pp. 26-33, 59).
- Prevalence of myopia has been correlated with level of family income, level of education of parents, refractive status of parents, reading ability, scholastic success, and intelligence (pp. 10-11, 60-61).

- Young adult myopes appear more at risk for myopic shift than nonmyopes. Some portion of young adults who became myopic as children progress after a period in which their myopia has become stable; others without myopia develop it as young adults. Although available onset data are difficult to analyze, they generally indicate that myopic shifts among low hyperopes and emmetropes are less frequent and less severe than among myopes. Medium and high hyperopes are less at risk for myopic shifts than others (pp. 22-24, 68-70).
- Military academies should collect standard refractive information about optical components of the eye (e.g. corneal curvature, lens power, length of eye) under controlled conditions. The necessary technology and human resources are at hand to determine the risk factors related to the causes, progression, optical components, and consequences of adult onset myopia. For example, the length of the eye can be followed to determine if those eyes that ultimately become myopic show early fundus signs (signs of change at the back of the eye) that would identify those eyes at increased risk of undergoing future elongation (pp. 39).
- It is important to know what anatomical or functional changes are responsible for young adult myopia. We therefore recommend that research be conducted to determine how each of the optical components of the eye contributes to refractive state and to refractive change (pp. 39).
- Study designs should be standardized so that the results of various investigators can be compared. Initial suggestions are offered, more to focus discussion that will lead to consensus than to propose them as final solutions (pp. 39-41).

1
Introduction

Myopia is the visual condition in which only nearby objects appear in focus, much like a camera permanently focused at a close distance. In a "normal" or emmetropic eye, distant objects are naturally in focus, like a camera focused at infinity. That is, the focal length of the optics of the eye (the cornea and lens) is appropriate to the length of the eye along the axis of these optical elements (the optical axis of the eye). The nearly parallel rays of light from distant objects are bent just enough to come together to form an image on the retina—the part of the eye that detects light. For a close object, the rays of light are diverging and a stronger lens is needed to bend them enough to form an image on the retina. This is done in the eye by increasing the optical power of the lens, an act called accommodation. In contrast, in a myopic eye, the essentially parallel rays from distant objects are bent too much to form an image on the retina; rather they would form an image in front of the retina. That is, the optical power of the relaxed eye is too great for its length.

Myopia can result either because the optical power of the eye is abnormally great or because the eye is abnormally long. Since eyes differ greatly in length and optical power, however, one often cannot say that one parameter is abnormal. Instead, it makes more sense to say that, in myopic eyes, the focal length of the optics of the eye is too short for the physical length of the eye. In the opposite condition—farsightedness or hyperopia—the optical power of the lens is too weak for the length of the eye, with the result that even the most distant rays are not bent enough to focus an image on the retina, unless the eye accommodates.

The measure traditionally used to express the degree of myopia or hyperopia (collectively called ametropia) is the power of the ophthalmic lens required to correct the optics of the eye so that parallel rays from distant objects fall on the fovea of the retina. A negative (concave) lens reduces the optical power of the eye; the more myopic the eye, the more powerful the negative lens required. The unit of measurement of lens power is the diopter (D.), which is the reciprocal of the focal length in meters. The more negative the value of the correcting lens, the greater the myopia. As an approximation, we can describe the degree of myopia as the difference between the focal length of the eye and its actual length (in reciprocal meters).

THE WORKING GROUP'S TASK

Between 15 and 25 percent of the adult population in the United States is unable to

see distant objects in sharp focus without spectacles or contact lenses. Almost all these individuals developed myopia after age 7, their myopia increasing in severity until the mid-teens. Typically, an individual's myopia remains relatively constant for the next 30 to 40 years. The evidence strongly favors a disproportionate elongation of the eyeball during growth as the optical basis for this juvenile-onset myopia.

Numerous reports suggest, however, based primarily on the population of young adults engaged in college study, that a significant number of individuals may develop myopia—or renew myopia progression—as they approach their 20s. The prevalence of myopia onset in young adults is unknown, although it has been reported to occur in as many as 20 to 30 percent of young men who enter U.S. military academies.

The impact of both juvenile and young adult myopia on the recruitment and retention of Air Force Academy students is substantial and has enormous economic and social consequences. Qualifications for military pilots currently specify no refractive error greater than −0.25 diopter (D.) of myopia in any meridian—although waivers may be granted for myopia up to −1.25 D. A high prevalence of myopia in the applicant pool necessarily places constraints on recruitment. Students who are either qualified at entry or have a waiver run the risk of losing their waivers for pilot qualification should they develop myopia greater than −1.25 D. by the time they complete four years of study. This poses a real problem for the U.S. Air Force, not to mention for students' career plans.

Obviously, without change in these refractive error standards, enormous cost and human savings could be achieved by the selection of applicants whose refractive error changes could be predicted to be zero or minimal during their training and professional careers. Even if this predictive power were available for the progression of young-adult-onset myopia, however, the armed forces are still faced with the problem of the size of the appropriate pool that is available with respect to refractive error. Clearly the prevalence of myopia in the young adult population, if it assumed major proportions, would be a severely limiting factor in the number of visually qualified applicants for special training in the academies, unless the visual criteria were changed. Consequently, it is of considerable interest to establish the prevalence of myopia among college-age individuals who are eligible for training and to determine if the applicant pool is decreasing significantly because of greater prevalence. Such a study would require a determination of how race, sex, education, socioeconomic status, and other factors are related to myopia. Furthermore, there is a need to understand and document how subsequent changes in refractive error can be predicted for young adults.

These concerns brought the U.S. Air Force School of Aerospace Medicine to the Committee on Vision. Through it the Working Group on Myopia Prevalence and Progression was asked to focus its discussion on these questions, purposely avoiding other important issues—such as etiology, the influences of near work and nutrition, and the effects of treatment—except as they bore on the central issues of the prevalence and progression of myopia.

As a first step in our efforts, we conducted an extensive literature review, identifying more than 500 articles published since 1812 in U.S. and European journals on the subject of myopia. These articles, identified by the working group members, were subsequently pruned to about 150 articles concerning prevalence and progression. These articles were formally annotated in detail according to the following headings: type of study, years for which data were collected, population, criteria for myopia, specific rates, major findings, limitations on interpretability, and summary. These annotated references formed a rich resource for the preparation of our subsequent literature reviews. In addition to carrying out the literature search, the staff explored the availability of published research findings in

Chinese, Japanese, and Russian, although the search of journals written in these languages was necessarily less exhaustive.

INTERPRETING THE MYOPIA LITERATURE

The working group conducted an extensive literature search to determine whether (1) there have been significant changes in the prevalence of myopia among young adults eligible for entry into U.S. military academies and (2) the nature of onset and progression of myopia among young adults. Certain problems arise, however, in interpreting this literature. Many authors do not make clear, for example, the characteristics of the study population, the measurement methods, or the criteria for myopia. Even when these factors are described, differences in defining them usually prevent direct comparative analysis of the studies. It is generally by interpretation of several studies—which have some criteria and characteristics in common—and by learning something of how specific factors influence comparisons, that we have gained certain insights into the prevalence and progression of myopia. Some of the difficulties we encountered in interpreting and comparing information from the published literature are described below.

Sample Characteristics

There are no studies of prevalence or progression of myopia among a completely randomized population that report complete classification or measurement criteria. Most prevalence samples are made up of clinic patients or students. Prevalence outcomes are probably affected by ethnic differences, socioeconomic factors, and educational levels. Therefore only those studies that compare similar ethnic groups, similar with respect to age distribution, gender, and socioeconomic backgrounds, can provide useful information concerning changes in prevalence over time.

A major problem in documenting gender differences in myopia prevalence is that they appear likely to be age dependent. The reporting of overall gender differences over a wide range of ages not only potentially obscures possible age-specific patterns, but also introduces the possibility of confounding by age distribution. Unfortunately, many studies are not large enough to allow stable estimates for age-specific gender comparisons, and statistical techniques that might allow for control of confounding or allow for age-gender interaction are not generally applied.

Samples in which progression is studied often change. For example, withdrawal from a sample may not be independent of the refractive error status of the subjects.

Measurement Methods

Some authors estimate prevalence or onset and progression of myopia by measures of distance visual acuity employing refractive techniques. Nineteenth-century investigators often used an ophthalmoscope to estimate refractive error by determining the lens power necessary to bring the retina into focus. Subjective or retinoscopic refractions provide data for some of these earlier studies and for almost all studies during this century. More recently, automated refractors have provided the data for a growing number of studies.

Cycloplegic refraction sometimes yields different results than noncycloplegic (i.e., drugless) refraction. Maximum temporary ciliary paralysis results from repeated application of atropine (though this is rarely done). Other cycloplegic agents vary in their effectiveness with such factors as method of application and refractive error. There are also individual variations in response to cycloplegia related to ocular pigmentation.

The results of different examiners employing different testing methods make comparisons of prevalence and progression difficult. In any event, the effect of measurement errors is greater the lesser the degree of reported myopia or myopic change.

Classification Criteria

A major problem in comparing data is due to classification criteria's not being reported, being significantly different across studies, or including very small degrees of refractive error. Prevalence studies ranged in classification of myopia from that greater than −2.00 D. to as little as −0.12 D. (Throughout the text, a negative sign indicates a change toward myopia, and a positive sign a change toward hyperopia.) Progression studies are also difficult to compare, especially when the change is less than −0.75 D. This is particularly true when different examiners, different instrumentation, or cycloplegic and noncycloplegic examinations are involved.

In progression studies, a difference in refractive error from one period to another is the primary measure; therefore, reliability of the measure is critical and may be diluted when different examiners perform refractions at the two testing periods. Even when estimates of reliability are reported, often little or no attempt is made to incorporate them into interpretation of the data reflecting myopic shifts. For example, most studies legitimately can report a reliability of ±0.25 D. for either cycloplegic or subjective refractive techniques. This means that a small number of subjects will show a shift of −0.75 D. or more simply due to measurement error. By comparison, a much larger group will show an actual shift of −0.25 D. or more. Despite this, many studies report shifts in myopia using −0.25 D. or less as the criterion for onset or progression of myopia. This would inflate the estimate of numbers demonstrating myopic shift, but probably not that of mean refractive changes in large samples. When classification criteria are known, the effect on prevalence data can be estimated. For example, we used a clinical population study (Hirsh, 1950) to derive the change in prevalence of myopia when the criterion for myopia is changed. If, instead of accepting myopia as −0.50 D. or more (used by many studies), we adopt a criterion of *any* minus refractive error, the prevalence level increases by a factor of 1.2. If the criterion now shifts from −1.00 D. or more to *any* refractive error, the prevalence increases by a factor of 1.5.

Some studies report myopia prevalence in terms of a negative refractive error in either eye, while others report one eye only. Estimates of prevalence are greater when both eyes are reported. The presence of astigmatism also provides a potential complication in comparing data from different investigations. Many studies report myopia in terms of spherical equivalent, whereby the refractive error is an average of the refraction in the two major meridians. Others report only a spherical component of the refractive error. This component can be expressed as two numerically quite different amounts, depending on whether the cylindrical (astigmatic) component is expressed in terms of "plus" cylinder or "minus" cylinder correction.

GUIDE TO THE REPORT

This report is organized as follows: Chapter 2 is our analysis of the prevalence literature, Chapter 3 is our analysis of the progression literature, and Chapter 4 lists our conclusions and recommendations. Separate appendixes contain a description of the biological basis of myopia (Appendix A), a detailed review of the prevalence (Appendix B) and the progression (Appendix C) literature, a description of the etiology of myopia (Appendix D), and a

glossary of terms for those unfamiliar with work in this field (Appendix E). The report concludes with a complete bibliography.

The detailed reviews of the prevalence and progression literature in Appendixes B and C differ from the analysis reported in Chapters 2 and 3 in that they focus on reviewing the literature, with minimal attempt to draw general conclusions. The appendixes provided the basis for the more selective analysis found in Chapters 2 and 3. For readers interested in a more comprehensive review of the literature, the appendixes provide an additional resource.

CONCLUSION

We are impressed with the diverse nature of myopia and the multiple factors that presumably contribute to it. Indeed, myopia is itself best thought of as the final consequence of variations in a number of biological, sometimes pathological factors influencing refraction in the human eye. Myopia may result, for example, from an abnormally steep cornea, a crystalline lens with greater than average thickness and power, or axial elongation of the eyeball. Alternatively, it may result from the mismatch of these optical components, even though each individual component itself is within the normal range of values. Finally, myopia onset in childhood may have a totally different basis than myopia onset in young adulthood. Understanding the growth of the separate dioptric components of the eye is important if significant progress is to occur in understanding the underlying causes.

Even though we encountered limitations in interpreting the literature on progression and prevalence of myopia, it was nevertheless possible to formulate some important conclusions. These conclusions led us in turn to recommend several actions to be undertaken both by the military community and by clinical investigators to achieve a better understanding of the mechanisms of myopia onset and progression.

2
Analysis of the Prevalence Literature

This analysis primarily addresses the issue of whether there have been significant changes over time in the prevalence of myopia among young adults eligible for military academy training. Prevalence studies can shed light on this question if as we assume the preponderance of myopia develops at an early age, and if the groups compared are similar with respect to gender, socioeconomic status, and ethnicity.

Our review of the literature suggests that the prevalence of myopia is not markedly different for populations under age 20 or 25 compared with those who are older.

We know that numerous new cases of myopia appear between the ages of 7 and 13, at least among populations of schoolchildren in all ethnic groups. Nonschool populations have not been studied sufficiently to determine whether onset of myopia among children is a general phenomenon or primarily affects only schoolchildren. However, onset of myopia in young adulthood appears to affect few except those who are college students or who enter intensive near-work environments.

Certain ethnic groups appear to have shown changes in prevalence over time. Myopia appears to have increased among Eskimo populations, to have varied over time in Japan, and by some reports to have decreased in Scandinavian countries. It appears that Caucasian populations display almost equal prevalence when clinic populations and more randomly collected samples are compared over time.

INFLUENCING FACTORS

In the myopia literature, it is seldom possible to estimate the degree of influence that variables of age, gender, socioeconomic status and ethnicity contribute to comparisons of prevalence. Criteria of sample selection and characteristics of the sample are seldom defined sufficiently to assess their influence in any precise way; however, by reordering or extending the analysis of an author's data, at least the direction of some of these influences sometimes can be taken into account.

Gender

Gender differences probably have little effect on the comparability of data in large samples distributed over a wide range. However, slight but significant gender differences in prevalence of myopia have been found between ages 10 and 15 among a wide range of Caucasian and non-Caucasian ethnic groups (Alsbirk, 1979; Angle and Wissmann, 1980a;

TABLE 1 Myopia Prevalence Among Children by Age and Gender, 1952 (percentage)

	Myopia -.12 D. or greater		Myopia -1.00 D. or less		Myopia -1.12 D. to -3.00 D		Myopia Greater than -3.00 D.	
Age	Females	Males	Females	Males	Females	Males	Females	Males
5-6	6.15	7.43	5.70	6.76	0.45	0.52	0.00	0.15
7-8	9.71	11.02	8.73	10.12	0.75	0.74	0.23	0.16
9-10	17.18	15.68	15.17	13.86	1.76	1.51	0.25	0.31
11-12	21.60	20.74	15.83	17.66	4.42	2.82	1.35	0.26
13-14	25.36	22.53	19.58	17.45	4.17	5.22	1.61	1.37

Adapted from Hirsch (1952).

Baldwin, 1957; Bjerrum and Philipsen, 1884; Hirsch, 1952; Pendse, Bhave, and Dandekar, 1954; Sperduto et al., 1983). Although Kempf et al. (1928) found no significant differences in Washington, D.C., schoolchildren, most other studies point to a slightly higher prevalence of myopia in females in this age group. Hirsch (1952), in a study of nearly 10,000 randomly selected California schoolchildren, determined prevalence of myopia at one-year intervals between ages 5 and 14 (Table 1). Sperduto et al. (1983) examined gender differences in myopia prevalence among a group in the United States not selected for visual characteristics and found significant differences for age groups between age 12 and about 30. Above age 30 no gender differences were apparent. For all ages within this range, estimated prevalence of myopia was 27.1 percent for females and 22.8 percent for males. Angle and Wissmann (1980a) also found higher prevalence for teenage girls that was not apparent at older ages. The gender differences in the early teens may be associated with sample selection or, more likely, with different ages of onset of puberty.

Other studies of the late teens and early 20s tend to show no significant differences with gender, suggesting that gender differences in myopia prevalence do not exist in young adult populations. For example, Pendse and Bhave (1951) found none at age 18, and Parnell (1951) found no differences among students of college age.

For adult samples, ranging from ages in the 20s to age 70 or older, small but consistent differences are often reported, with males exhibiting slightly higher myopia prevalence. Witte (1923), for example, found that, in a sample of 34,000 adult subjects in Germany, 13.8 percent of the females and 16 percent of the males were myopic. Alsbirk (1979) also reports a higher prevalence of myopia at or above −0.12 D. for males above age 40 (48 percent males versus 26 percent females). Curiously, he reports this gender prevalence reversed for the age group 15-30 (42 percent females versus 29 percent males). The adult prevalence figures already cited by Sperduto et al. (1983) and Angle and Wissmann (1980a) suggest no significant gender differences.

While the number of cases is sufficiently small to have little effect on prevalence of myopia generally, all studies of severe myopia show much greater prevalence among females. In Hirsch's (1953) sample, female myopia above −7.00 D. was 2.5 times more prevalent. Blegvad (1927) and others (Schmerl, 1949; Schwartz and Andberg, 1954) found prevalence for myopia above −6.00 D. greater in females (2.65 versus 1.14 percent).

Reports from various countries and studies of various ethnic groups suggest that severe myopia has been much more common among females worldwide for at least the last century, but that the incidence of severe myopia has decreased significantly in Europe and the United States.

Socioeconomic and Educational Factors

In the myopia literature, it is usually difficult to isolate socioeconomic factors unless the sample is controlled for ethnicity. Such studies show that certain social, economic, or cultural factors are related positively to myopic prevalence. In all countries for which data were reviewed (see Appendix B), the most consistently reported differences were associated with differences in educational level or attainment; some of these are confusing because of failure to separate the influence of educational level from that of age. Hirsch (1959) found that myopes scored above the mean on the Stanford-Binet test, and hyperopes below; Young (1963), Grosvenor (1970a), and others (Baldwin, 1981; Jahoda, 1962; Nadell and Hirsch, 1958) have reported that myopes are more successful in scholastic work. The latter result has been found more consistently than the former. Inconsistencies in studies equating intelligence with myopia have added to the controversy concerning whether myopes read more, or whether reading produces more myopes.

One example of the relationship between family income and myopia is offered by the Angle and Wissmann (1980a) study. When family income was at the upper end of the income range studied, they found the prevalence of myopia to be above 40 percent. When family income was at the lower end, myopia prevalence was about 20 percent. Sperduto et al. (1983) found a higher prevalence of myopia among children in higher-income families. Young et al. (1954a) found the prevalence of myopia significantly higher among children of a university faculty than among children of farmers living in the same region. Family income was not related to prevalence of myopia. They found a low positive correlation between time spent reading and myopia at ages 6 to 12, and a high correlation at ages 12 to 17.

Ethnicity

Attempts have been made to assess prevalence over time among single ethnic groups. The most comprehensive investigation was undertaken by Goldschmidt (1968), who compared prevalence data from Denmark and Norway collected in 1882 by Tscherning with the data he himself collected in 1968. Goldschmidt concluded that there had been no significant change in prevalence of myopia of low and moderate degree, but there was a sharp decline in severe myopia. Fledelius (1983) reached the same conclusions concerning mild, moderate, and severe myopia when he studied myopic prevalence of a patient population after excluding those who were diabetic. Other earlier reports suggest a decrease in prevalence of mild and moderate myopia among Scandinavian populations (Ask, 1904; Blegvad, 1918; Heinonen, 1924; Holm, 1925). Significant decrease in prevalence of severe myopia during this century has also been reported by several Scandinavian authors as well as those in other European countries (Barfoed, 1953; Heinonen, 1934; Laatikainen and Erkkila, 1980).

Tamura (1932) found 12 percent of a clinic population in Japan had myopic greater than −1.00 D. and less than −10.00 D. He compared this figure with that calculated from patient files recorded in 1911, when 5 percent were found to be myopic within that range. He reported that severe myopia was less prevalent in 1932 than in 1911. Sato (1957) reported that prevalence had increased from 15 to 45 percent, when records of middle-school children in Japan were examined for the years 1914 and 1955. However, both Sato

(1965) and Otsuka (1956) concluded from their own studies and those of others that there was a marked decrease in prevalence of myopia in Japan between 1940 and 1950, followed by a reversion to earlier higher prevalence rates.

The most consistent reports of significant increase in prevalence come from studies of Eskimo populations. Bind (1950) found almost no myopia among Eskimo children. Skeller (1954) reported that myopia was exceptionally rare among all Eskimos. Young et al. (1969) reported that, in a majority of the population living in one Eskimo community, virtually no myopia existed among Eskimo parents and grandparents, while more than half the children of school age were myopic. Morgan and Munro (1973) found a prevalence of 30 percent among an Eskimo population between ages 15 and 20 and less than 10 percent among those above 30 years of age. Alsbirk (1979) found relatively high prevalence among Greenland Eskimos at all ages.

Otsuka and Sato disagree concerning the causes of myopia, but both attributed the temporary decrease in prevalence to changes in education in Japan during World War II and its subsequent increase to resumption of the heavy reading demands placed on students. Increased prevalence of myopia among Eskimos has been attributed to the advent of compulsory education, although changes in diet and the introduction of artificial lighting may also be implicated. Goldschmidt's analysis (1968) and reports of other Scandinavian authors provide the most conclusive evidence that there has been a long-term stability of myopia prevalence in a population that might be compared to our own. The studies cited provide the only comparisons within ethnic groups that were found to offer clues concerning prevalence trends.

ADULT SAMPLES

In addition to variation in the selection factors listed above, comparison of data from different studies is made even more hazardous by differences in measurement and classification criteria (see, for example, Grosvenor, 1987) and by failure to identify crucial design characteristics. Despite these problems, however, certain interpretations can be made. Prevalence results found by Scheerer (1928) and Betsch (1929) in Germany are similar to those of three other investigations conducted in the United States at about the same time (1925 to 1940). Comparison suggests that adult populations, which are primarily Caucasian, show similar degrees of prevalence in different countries. Table 2 shows prevalence figures for adults in the four samples. Jackson (1932) and Tassman (1932) divided their samples into two age groups and found no significant difference in prevalence. Brown and Kronfeld (1929) reported that no difference in prevalence existed between a large sample of patients divided into two groups older than and younger than age 25.

Four of the five broad population studies cited in Table 2 (Scheerer and Betsch [combined data], Jackson, and Tassman) are taken from records of ophthalmic clinics and private practices. The fifth (Walton, 1950) is made up of the adult residents of a home for the indigent. Scheerer and Betsch examined the records of more than 25,000 adults over age 25. They excluded records of patients showing more than 1.00 D. of astigmatism and patients who reported asthenopia as their chief complaint. The right eye subjective spherical components of the least plus or the highest minus were recorded. When compared with studies using spherical equivalents, this procedure would create a myopia bias; however, the degree of bias would be slight, because only astigmats of 1.00 D. or less were included in the study.

Walton (1950) reported that only 1.8 percent of those in his study (n = 1,000) showed simple myopic astigmatism; 4.8 percent showed mixed astigmatism. All those with 1.00

TABLE 2 Studies of Myopia Prevalence Among Adults in Various Populations, 1928-1950 (percentage)

Investigator	Year	N	Age Range	Prevalence Total Group	Lower Age Group	Higher Age Group	Age at Which Group Divided
Scheerer (1928); Betsch (1929)	1928	25,000	25-70+ yrs.	13.7	-	13.7	25
Jackson (1932)	1932	8,013	5-60+ yrs.	17.1	16.6	17.4	20
Tassman (1932)	1932	8,764	5-70+ yrs.	18.9	17.6	17.9	20
Walton (1950)	1950	1,000	30-90 yrs.	17.7	-	17.7	30

D. of astigmatism or less would be included in Scheerer's study; the portion of this small percentage who had spherical components of no greater than +0.25 D. sphere with −0.50 or −0.75 D. minus cylinder, or no more than +0.50 D. sphere with −0.75 or −1.00 D. minus cylinder, would be included in Scheerer's prevalence data. Since none of the studies to which the Scheerer data are compared included spherical equivalents of −0.25 D. or less in myopia prevalence data, the Scheerer and Betsch studies are not biased toward higher prevalence than actually exists; there is in fact a small bias in the opposite direction. The grouping technique of the other studies eliminates those myopes whose subjective refraction (usually without cycloplegia) was no greater than −0.37 D. in the meridian of the least plus (or the highest minus) power. Scheerer and Betsch's data can be classified according to prevalence of myopia of various degrees so that some comparisons can be made with Walton's data (Table 3).

Brown and Kronfeld took precautions to eliminate tonic accommodation in their study. Atropine was administered an average of three times each day for three days before refractive tests were taken. Despite the fact that only about one-third of Scheerer's patients were examined under cycloplegia using homatropine, the difference in mean refraction of the two groups is slight (+1.00 D. versus +0.50 D.). The Brown and Kronfeld result presumably was the average for all four meridians, with the same effect in the calculation of means as in determining spherical equivalent. Scheerer's mean is based on the least hyperopic or most myopic meridian of the right eye. The mean difference between the two principal meridians approximates 0.50 D. Some of the difference in means between the two studies is as likely to be the result of this factor as the result of differences produced by the use of a cycloplegic agent.

Thorough atropinization prior to refraction can be expected to create some difference in subjects who are prepresbyopic when compared with cycloplegic refraction using homatropine or noncycloplegic refractions. The effect has usually been found to be greater for hyperopic subjects than for those who are myopic. Bothman (1932a) found that this effect is greater in both hyperopia and mixed astigmatism than in myopia (+1.00 D. mean difference versus +0.50 D. mean difference). Bannon (1947) found no significant difference between the refraction of myopes of any age without cycloplegia and with cycloplegia using homatropine. He found a mean difference of 0.50 D. among children and 0.25 D. among adults

TABLE 3 Myopia Prevalence of Various Degrees Among Adults, 1929-1950

Spherical Equivalent Refraction	Scheerer (1928) & Betsch (1929)	Walton (1950)
-.62 to -1.50	5.5	7.8
-1.62 to -2.50	2.5	3.4
-2.62 to -3.50	1.5	2.4
-3.62 to -4.50	1.0	0.7
-4.62 to -5.50	.5	0.5 (-5.50 to -8.00)
-5.62 to -6.50	.5	1.0 (-8.25 to -11.00)
-6.62 to -10.50	2.0	>0.1 (-11.25 to -14.00)
-10.62 and greater	1.0	>0.1 (-14.25 and over)

who were hyperopic. Both Bothman and Bannon used the same procedure for administering homatropine. Young et al. (1971) compared refractions performed with and without cycloplegia in Eskimos. They reported greater mean reduction of myopia after cycloplegia than did Bannon. Young and his colleagues utilized a 2 percent solution of Cyclogyl.

Sato (1964), employing atropine in a study in Japan, reported greater differences for myopes than the mean change reported by Bothman. In separate studies involving a large number of children, Sato (1957) and Otsuka (1967) reported that hyperopic shifts can be observed following atropine cycloplegia in eyes exhibiting low myopia or emmetropia during drugless refraction. (The English translations cited above did not indicate the magnitude of the hyperopic shift.)

Jackson (1932) excluded patients with eye injuries, ocular disease, and those who were monocular. Cycloplegic examinations were conducted on all patients who were not advanced presbyopes. He employed spherical equivalents and identified myopia as −0.50 D. or greater. Tassman (1932) determined spherical equivalents for more than 9,000 patients without ocular disease. He classified myopia in the same way as Jackson. Walton (1950) determined manifest refraction of 569 male and 431 female adults residing at a home for the indigent in Philadelphia. When astigmats are removed from the sample as they were in the Scheerer and Betsch study, 16.9 percent of Walton's group exhibited myopia greater than −0.25 D. Some proportion of the 1.8 percent who displayed simple astigmatism should be added to this figure for comparison with the other three studies, as should some indeterminant but small percentage of the 4.8 percent of mixed astigmats. As indicated earlier, Walton's data (excluding astigmats) is compared in Table 3 with those of Scheerer as to the percentage of the sample that exhibits myopia at various dioptric intervals. Brown and Kronfeld and Betsch and Scheerer reported that, while their samples were comprised of clinic patients, the distribution of refractive errors was similar to that of the general population, after the records of diseased eyes were removed. They based this on the

high frequency of emmetropia in their samples and comparison of mean refractions within certain age groups in their samples with means of small random samples at the same age. These studies form a benchmark to which nineteenth-century and late twentieth-century investigations of prevalence can be compared.

Several additional studies reinforce the conclusion that Caucasian adult samples are similar and have been stable throughout this century. Clarke (1925) reported 19 percent prevalence in an adult population in England, although his population characteristics and evaluation criteria were insufficiently described to authenticate comparison. A 1962 survey by the British Ministry of Health (Bennett and Rabbetts, 1984) of 9,163 prescriptions for distance vision indicated that 23 percent were worn for myopia of −0.37 D. or greater (spherical equivalent, right eye). Rasmussen (1948) collected several hundred serial case records from ophthalmic practices in each of 68 cities in England and Scotland. He reported that prevalence of myopia among all ages was similar in the two countries (26 percent spherical equivalent greater than −0.25 D.). Von Reuss (1877) and Witte (1923) found similar prevalence of myopia among two clinic populations in Germany (14.5 percent and 13.8 percent). They appear to have employed similar classification criteria (greater than −0.75 D.). Hirsch (1958) found prevalence of myopia greater than −1.00 D. to be 8.8 percent in a U.S. clinical sample older than age 44. Prevalence cf myopia of −0.50 D. and above in Hirsch's population is calculated to be 18.1 percent.

CHILD POPULATIONS

Prevalence studies have been conducted among groups of primarily Caucasian children as young as age 5 and as old as age 17. Compared over time these studies can provide some evidence concerning major changes, if any, in prevalence of myopia among young adults. Older studies clearly involve different populations compared with more recent studies, due to the effects of such factors as mandatory school attendance. Comparison of these studies should therefore be interpreted with caution.

Children ages 5 to 17 and college-age students represent the largest number of investigations reported. The earliest report discovered concerning schoolchildren is that of Schurmayer (1856), who between 1839 and 1850 examined 2,172 German schoolchildren between ages 8 and 16: 18 percent were reported overall to be myopic; 35 percent of those ages 14-16 were myopic. These and other prevalence figures among schoolchildren cited later are presented in Table 4. Von Jaeger (1861) reported that 55 percent of a group of boys in a school for orphans were myopic; his study was based on ophthalmoscopic estimates. Using the same technique, Cohn (1867) found that 1.4 percent of 5-6-year-olds in a village school were myopic greater than −1.00 D. but that this increased to 55.8 percent of 16- and 17-year-olds. After instilling atropine, Cohn (1886) found an average of 1.00 D. less myopia (or more hyperopia), which reduced the prevalence to about 20 percent.

In the United States, Conrad (1874) compared the results of ophthalmoscopic estimates of refractive status with subjective refraction. He obtained higher prevalence rates of myopia from subjective testing (32 versus 22 percent). Cohn (1892) later made this same comparison and reported no significant difference in the prevalence rates obtained. Florschutz (1880) calculated myopia to be 21 percent among a group of 2,000 German schoolchildren ages 11 to 16. Hess and Diedricks (1894) found 26.8 percent prevalence among a group of German children ages 10 to 14.

Studies in Sweden (Ask, 1904, 1925; Blegvad, 1927; Heinonen, 1924), Finland (Laatikainen and Erkkila, 1980; Mantyjarvi, 1983), the Soviet Union (Mogilevchik and Bondareva, 1970; Popov, 1931), and Denmark (Bjerrum and Philipsen, 1884; Blegvad, 1918; Fledelius,

TABLE 4 Studies of Myopia Prevalence Among Children in Europe and the United States, 1831-1980

Investigator	Country	Year Reported	Prevalence (%)	Age Range (years)	N	Relevant Criteria
Schurmeyer	Germany	1856	19.0	8-16	2,172	Refraction
			35.0	14-16		Refraction
Von Jaeger	Germany	1861	55.0	9-16	Small	Ophthalmoscope; orphan school
			80.0	9-16	Small	Ophthalmoscope; private school
Cohn	Germany	1864	1.4	5-7	10,060	Ophthalmoscope myopia >1 D.
Cohn	Germany	1867	9.9	6-16		Ophthalmoscope
Florschutz	Germany	1880	21.0	11-16	2,041	Ophthalmoscope
Hess and Diedricks	Germany	1894	26.8	10-14		
Ware	England	1831	<1.0	Lower school	1,300	Not known
Thompson	Scotland	1919	18.8	High school	3,249	Clinic sample
McIllroy and Hamilton	England	1932	21.6	6-14	1,702	Noncycloplegic
Sorsby	England	1932	4.0	4-14		Cycloplegic
McNeill	England	1955	21.2	5-15	1,066	Clinic sample
Popov	USSR	1931	2.4	8-10		Not known
Mogilevchik and Bondareva	USSR	1970	10.0			Not known
			3.1	Lower grades		Not known
			23.7	Upper grades		Not known
Nicati	France	1879	15.0	7-12	1,717	Not known
Dor	France	1878	22.0	12-16		Not known
Bjerrum	Denmark	1884	10.6	13-14	198	>-1.50 D.
Philipsen	Denmark	1884	12.4	13-14	210	>-1.50 D.
Laatikainen and Erkkila	Finland	1980	1.9	7-9		Not known
			21.8	14-16		Not known
Conrad	U.S.	1874	32.0	6-16		Subjective refraction
			22.0	6-16		Ophthalmoscope
Agnew	U.S.	1877	10.0	Grade 1-4		Ophthalmoscope
			14.0	Grade 5-8		Opthalmoscope
			16.0	Grade 9-12		Ophthalmoscope
Loring	U.S.	1876	4.0	6		Not given
			26.0	21		Not given
Kempf	U.S.	1928	7.1	6-18	1,828	>-.25 D. (cycloplegia)
			2.1	6-8	333	>-.25 D. (cycloplegia)
			5.5	9-11	495	>-.25 D. (cycloplegia)
			9.5	12-18	1,001	>-.25 D. (cycloplegia)
Jackson	U.S.	1932	8.1	5-10	227	-.50 D. (cycloplegia)
			16.1	10-15	414	-.50 D. (cycloplegia)
			25.7	15-20	611	-.50 D. (cycloplegia)
Tassman	U.S.	1932	8.6	5-10	148	-.50 D. (cycloplegia)
			19.5	10-15	403	-.50 D. (cycloplegia)
			24.7	15-20	421	-.50 D. (cycloplegia)
Hirsch	U.S.	1952	24.0	13-14		>-.12 D. (noncycloplegic)
			5.4	13-14		≥-1.00 D. (noncycloplegic)

TABLE 5 Studies of Myopia Prevalence Among Schoolchildren at Different Ages in the United States, 1877-1932

Agnew (1877) (unknown)		Kempf et al. (1928) (≥ -.25 D.)		Jackson (1932) (≥ -.50 D.)		Tassmann (1932) (≥ -.50 D.)		Hirsch (1952) (≥ -.12 D. and ≥ -1.0 D.) % Myopic[a]		
Grade	% Myopic	Age (years)	% Myopic	Age (Years)	% Myopic	Age (years)	% Myopic	Age (years)	-.12D. and above	-1.0D. and above
1-4	10	6-7	1.4	5-9	8.1	5-9	8.6	5-6	6.8	0.6
5-8	14	8-9	4.2	10-15	16.1	10-15	19.5	7-8	10.4	1.0
9-12	16	10-11	8.5	5-15	13.3	5-15	14.6	9-10	16.7	2.0
		12+	9.1					11-12	21.2	4.5
								13-14	24.0	5.4

[a]Prevalence at various ages for varying degrees of myopia constructed from Hirsch's data.

1981b; Goldschmidt, 1968; Heinonen, 1924), as noted earlier, report similar prevalence rates.

McIlroy and Hamilton (1932) found a prevalence rate of 21.6 percent among 1,700 English schoolchildren ages 5 to 14. McNeil (1955) found 21.2 percent among a group ages 16 to 18. Thompson's (1919) data for schoolchildren in Scotland are comparable. Table 4 lists prevalence findings of these and other European investigators as well as those from studies in the United States.

The first U.S. study involving a large sample at a specific time was reported by Agnew in 1877. He examined 1,479 children by Cohn's ophthalmoscopic technique and found that this method did not yield a higher prevalence than did subjective refraction. Cohn (1892) and Derby (1880) also reported that ophthalmoscopic estimates of refraction gave results similar to those using other methods. Table 5 shows changes Agnew found with age along with those reported by later investigators. He concluded that prevalence in U.S. schools was similar to what Cohn (1886) found in Breslau and reported from studies in other European countries. Differences in prevalence reported in early studies are as likely to be due to variations in classification and testing methods as to actual differences in prevalence.

Kempf et al. (1928) examined retinoscopically (under cycloplegia) 1,860 white schoolchildren in Washington, D.C. Table 5 shows prevalence for each age group classified. The study included as myopic all those showing spherical equivalents of −0.25 D. or greater and all myopic astigmats. Mixed astigmats (less than 4 percent of Tassman's and Jackson's 1932 samples) were excluded. In Jackson's sample 13.3 percent of children in the age range 5 to 15 were −0.50 D. myopic or greater. Tassman's sample can be treated in the same way and yields a 14.6 percent prevalence rate. These figures, as well as prevalence rates from their studies for children ages 5 to 10 and 10 to 15, are presented in Table 5.

Hirsch (1952) studied refractive characteristics in a large population of California schoolchildren. He did not report prevalence figures for comparable subgroups, but they can be calculated from his data (see Table 5). Hirsch identified myopia as the spherical equivalent of −0.25 D. or greater. About 24 percent of the children between ages 13 and 14 (nearest birthday) were myopic by this criterion (18.5 percent were less than −1.00 D. myopic). The age group of 5-6 years had a prevalence rate of 6.8 percent (6.2 percent were less than −1.00 D. myopic). Angle and Wissmann (1980a) reported prevalence rates of

29.9 percent at 12 years and 33.2 percent at 17 years. Sperduto et al. (1978) determined prevalence rates to be 24 percent at age 12, and 27.7 percent among the ages 18-24. They analyzed data from general health surveys completed several years earlier but did not adequately describe their classification criteria. Their samples were relatively unselected, as were those of Hirsch and Kempf.

Some studies suggest that prematurity may be a risk factor for juvenile myopia. Castren (1955) examined 697 schoolchildren, 480 of whom were premature at birth. Those showing −0.50 D. spherical equivalent or greater were classified as myopic. Homatropine subjective refractions were performed. Approximately 5 percent of 109 children who had a birthweight between 1,000 and 2,000 grams were myopic, while 2.3 percent of the 217 children in the full-term control group (2,500 to 4,000 grams) were found to be myopic. Fletcher and Brandon (1955) and others (Birge, 1956; Fledelius, 1981a; Gerhard, 1983; Jain and Garg, 1970; Lledo, 1976) have reported that premature infants are at risk for myopia. In a retrospective study of high myopes (probably −6.00 or more), Fletcher and Brandon (1955) found that 90 percent of those whose birthweights could be determined weighed less than 1,500 grams at birth. While this is expected to have little influence on prevalence rates of large populations, it may be added to the list of risk factors for juvenile myopia (and conceivably young adult myopia as well).

Variations among these U.S. studies can be interpreted to some degree. There is little if any evidence of major differences in prevalence of myopia among Caucasian schoolchildren over the past 100 years, after correction for age and selection and classification criteria are considered. This conclusion probably also applies to comparisons of U.S. and European studies.

The conclusions of early investigators (Cohn, 1867; Dor, 1878; Florschutz, 1880; von Jaeger, 1861; Ware, 1813) that groups of children in more intensive educational environments exhibit higher prevalence of myopia were not corroborated until recently. A recent study of New Zealand native children (Grosvenor, 1986) disclosed a significantly higher prevalence among those who were involved in intensive study than those who were not.

YOUNG ADULT POPULATIONS

Another large group of studies of myopia prevalence includes young adult populations. However, none can be identified as unselected samples. A few of the general clinic populations can be classified into one or more age groups between ages 17 and 25 but most deal with highly selected populations—usually military recruits or students.

Clinic and General Populations

Young adult clinic populations can sometimes be extrapolated from studies of broader age ranges. Differences are generally in directions that could be predicted when the sample characteristics and the study design criteria are given. For U.S. studies in the 1930s, the clinical populations in Jackson (1932) and Tassman (1932) were divided into two age groups: 15 to 19 and 20 to 29. Both applied the criterion of −0.50 D. or greater (spherical equivalent) to identify myopia. The 15- to 19-year-olds exhibited 25.7 percent myopia in Jackson's study and 24.7 percent in Tassman's study. The 20- to 29-year-olds exhibited 19.6 percent myopia in Jackson's study and 22 percent in Tassman's study. All these figures are lower than those found in most studies involving undergraduates and all studies of older or upper division students. Table 6 lists studies that provide comparisons between two groups, each of which involves a significant number of subjects.

TABLE 6 Studies of Myopia Prevalence Among Young Adults By Age and Other Variables, 1848-1953

Investigator	Year Reported	% Myopia Group A	Group B	Source
Szokalsky[a]	1848	13.0 (1st yr. college)	17.0 (upper division)	France
Loring	1877	26.0 (U.S.)	63.0 (German)	College students
Loring	1877	26.0 (U.S.)	44.0 (Soviet)	College students
Agnew	1877	29.0 (precollege)	37.0 (seniors)	College students
Derby	1880	35.4 (at entrance)	47.2 (at graduation)	College students
Collard[b]	1880	23.0 (scientific and professional)	42.0 (humanities)	College students
Collard[b]	1881	30.0 (ages 17-22)	27.0 (ages 24-27)	
Tscherning	1882	2.4 (farmers & fishermen)	32.4 (advanced students)	Military recruits
Seggel	1884	2.4 (farm workers)	56.7 (compositors & writers)	Military conscriptees (Germany)
Jackson	1932	25.7 (ages 15-19)	19.6 (ages 20-29)	Clinic sample
Tassman	1932	24.7 (ages 15-19)	22.0 (ages 20-29)	Clinic sample
Boynton	1936	18.2 (at entrance)	23.9 (at graduation)	College students with visual acuity 20/50 or worse -1.50 D. or above
Nakamura	1954	20.0 (Caucasian)	30.0 (Nisei)	Military recruits
Sutton and Ditmars	1970	45.0 (at entrance)	60.0 (at graduation)	West Point cadets
Gmelin	1976	51.0 (at entrance)	67.0 (at graduation)	West Point cadets
Roberts and Rowland	1978	29.9 (age 12)	33.2 (age 17)	General
Sperduto	1983	23.9 (ages 12-17)	27.7 (ages 18-26)	General
Fledelius	1983	32.6 (-.25D. or above)	10.3 (-1.75D. or above)	Clinic sample

[a]Cited by Cohn (1967)
[b]Both studies cited in Collard (1881).

Sperduto et al. (1983) analyzed a subset of the data from the National Health and Nutrition Examination Survey (NHANES) collected in the United States between 1971 and 1982 (Roberts and Rowland, 1978). They report a slight decline in myopia prevalence, from 27.7 percent among 18- to 24-year-olds to 24-25 percent in the older groups.

In school year 1919-1920, fewer than 17 percent of students enrolled in high school graduated (U.S. Department. of Education, 1981). By the early 1960s this figure reached about 70 percent and has stayed at this level into the 1980s (U.S. Department of Education, 1981). By the mid-1970s, a little over 50 percent of high school graduates enrolled in college (U.S. Department of Education, 1981). Even if we make the unlikely conservative assumption that this was also true in 1920, we conclude that in the 1920s less than 8

percent of the adult population had attended or were attending college; by comparison, in the mid-1970s the comparable percentage would be 35 percent.

Despite this large difference in the adult populations of the 1920-1930 and 1970 periods, studies of prevalence of myopia fail to reflect significant differences for the two periods (Tassman, 1932; Brown and Kronfeld, 1929; Jackson, 1932; Sperduto et al., 1983). How can this be accounted for? First, it may be that, although the percentage of the population who attended college has increased since the 1920s, the proportion of individuals engaged in intensive near work may not have changed as dramatically. Unfortunately, good noncollege data for myopia prevalence are not available for those two periods. Second, it may be that the data used for these comparisons are simply not precise enough to reflect real changes in myopia prevalence between the two periods. Third, the myopic changes observed during the college years may be transient for a significant number of individuals and therefore do not appear in population studies that include a large proportion of individuals beyond college age. Finally, some combinations of these factors, and others, may be needed to account for the apparently paradoxical observations that, although myopia prevalence is significantly higher in college students than noncollege students and a much larger proportion of individuals attend college now compared with the 1920s, the limited adult population studies fail to reveal significant changes in the prevalence of myopia for the two periods.

College Students

College students represent the most accessible group for study within the young adult population. Studies of prevalence among college students in the United States and in Europe probably provide best evidence that prevalence is similar in both areas and over time. Among those prevalence rates listed in Table 6 are several for students ages 17-22.

Ware (1813) was the first to report prevalence among college students: he found that 25.2 percent were myopic. His and other prevalence figures of college students are given in Table 7. Schuster (1911) reported that 18 percent of Oxford undergraduates "have distinctively bad eyesight" but gave no explanation concerning the derivation of this figure. This corresponds closely with Parnell's (1951) prevalence figure of Oxford undergraduate males with visual acuity of 6/60 or worse. Parnell also found 49.9 percent prevalence among a group of male students representing all undergraduate levels at the same university when he employed visual acuity worse than 6/9 as his criterion. It can be expected that almost all who exhibit this visual acuity at that age would be myopes of greater than −0.25 D. spherical equivalent (Peters, 1961).

Several studies in Germany provide prevalence data for college students (Cohn, 1881; Durr, 1883; Erismann, 1871; Fleischer, 1907; Pfluger, 1875; Van Anrooy, 1884). The highest prevalence (58 percent) reported was by Seggel (1878); the lowest (30 percent) was reported by Collard (1881). Seggel's sample was comprised of older students. It may be presumed that they had spent more years in collegiate study. Several studies have reported a similar slight decrease in prevalence after age 20. This is most likely due to the addition of nonstudents to samples at older ages and, in clinic samples, to the failure of adults whose myopia is stable to seek care. Longitudinal studies seldom report significant decreases in myopia before age 40.

Randall (1885b) examined reports from a large number of investigations in various European countries and in the United States. The data permitted comparison of prevalence of myopia among secondary school and college students; the total number of subjects was over 40,000. About 28 percent of the total group was calculated to meet his criterion for

TABLE 7 Studies of Myopia Prevalence Among College Students in the United States and Other Countries, 1871-1985

Investigator	Year	Prevalence %	Location
College Students in the United States			
Derby	1877b	35.0	Harvard
Derby	1880	35.0	Amherst (lower division)
Derby	1882	47.2	Amherst (upper division)
Randall	1885b	52.5	Composite of 6 European and 2 U.S. studies (2,436 subjects)
Hall	1935	35.0	Washington
Dunphy	1968	44.0	Harvard (Business and Law Schools)
Septon	1984	75.0	Optometry students
Schell et al.	1985	81.0	Optometry students
Agnew	1887	28.5	Brooklyn Polytechnic
Agnew	1887	40.0	New York College
Burnett	1911	15.0	University of California
College Students in Other Countries			
Erismann	1871	43.0	Germany
Pfluger	1875	40.0	Germany
Kotelmann[a]	1877	49.0	England
Seggel	1879	81.0	Germany
Cohn	1881	53.0	Germany
Collard	1881	30.0	Germany
Durr	1883	35.0	Germany
Van Anrooy	1884	31	Germany
Fleischer	1907	50.0	Germany
Ware	1813	25.2	England
Smith	1880	20.0	England
Clarke	1924	20.0	England
Parnell	1951	32.0	England
Emmert[a]	1876	76.0	Switzerland
Francesschetti	1935	24.0	Switzerland
Vogt		24.0	Switzerland
Tscherning	1882	32.4	Denmark
Tamura	1932	12.0	Japan
Banerjee	1933	35.0	India
Li and Rush	1920	55.0	China

[a]Cited by Randall (1885b).

myopia (−0.25 D. or greater). Of college-age groups that permitted calculation, 52.5 percent met this criterion. According to Randall there were no clear differences in prevalence among entering college students. Table 7 presents prevalence figures from studies of college students in the United States and other countries for which some variations in study criteria could be assessed.

Military Personnel

Applicants to the U.S. Naval Academy and the U.S. Air Force Academy must meet special visual requirements that preclude their inclusion in prevalence evaluations. However, the U.S. Military Academy at West Point reduced vision requirements for admission in 1960. Socioeconomic and scholastic characteristics of those entering West Point in 1971 were compared with those enrolling in American colleges that year (Houston, 1972). They appear to be similar in those characteristics surveyed that are related to myopia prevalence. Sutton and Ditmars (1970) determined the mean spherical equivalent refractions of those entering from 1964 to 1968. They reported 45 to 51 percent of members of classes entering during that period were myopic on the order of −0.25 D. or more. On the basis of differences in frequency of refractive errors between this amount and that found by other investigators (whose criteria for myopia are known), this range appears to be similar for college students and military cadets. Gmelin (1970) found the prevalence of myopia among the entering class at West Point to be 51 percent.

Several studies comparing young male military recruits of different backgrounds provide evidence concerning differences in prevalence among socioeconomic classes, similarities between Caucasians in Europe and the United States, and stability of prevalence with time.

Ware (1813) reported that "among officers of the Queen's Guard many were myopic, while of 10,000 footguards less than half a dozen were myopic." Parnell (1951) compared unaided visual acuity of 279 male undergraduates at Oxford University to prevalence figures for over 90,000 18-year-old males from England and Wales who took National Service Board examinations in 1939. The Oxford students had a higher prevalence of low visual acuity at all levels (6/9 or less, 49.9 versus 11.4 percent; 6/60 or less, 16.8 versus 2.6 percent). Tscherning (1882) examined records of 38,670 Danish recruits and found a prevalence of myopia of −1.50 D. or greater in 8.3 percent of the group. Prevalence ranged from 2.4 percent of farmers and fishermen to 32.38 percent of advanced students. Seggel (1884) compared prevalence of myopia of the same magnitude among German conscripts and reported 2.4 percent for farm workers and 56.7 percent for compositors and writers.

Goldschmidt (1968) designed a study to compare results with Tscherning's data. He reported a prevalence of 9.2 percent among a large group of Danish draftees. The differences in prevalence between various occupational groups were similar to those reported by Tscherning 84 years earlier. After correcting his data for differences in representation of occupational groups, he reported that the difference in prevalence (8.3 percent for Tscherning versus 9.2 percent for Goldschmidt) disappeared. Many of the factors affecting prevalence fortuitously or by design were similar in all three studies, including age, the mean of which was approximately 20 in each. Stromberg (1936) found myopia of −1.00 D. or greater in 4.8 percent of 20-year-old males who were entering the Swedish army.

Steiger (1913) in Germany and Sorsby et al. (1960) in England found 13.1 percent and 11.6 percent, respectively, employing the same classification criterion for myopia. Steiger's sample was made up of males ages 20 to 30 from a clinic population. Sorsby's sample consisted of young men called up for national service.

Nakamura (1954) compared prevalence of myopia among Caucasian and Nisei recruits

in 1954 and found 20 and 30 percent, respectively. The difference between these two groups is probably real, reflecting an ethnic difference in prevalence. The percentage exhibiting myopia in the Caucasian group is similar to those reported above. Nakamura considered all myopic who had a spherical equivalent of –0.50 D. or greater (see Table 6).

3

Analysis of the Progression Literature

The characteristics of myopic onset and progression between ages 7 and 16 are such that it can be considered epidemiologically as a distinct form of myopia—and the most common. In addition, evidence is mounting that myopia that has its onset (or that increases after stabilizing in the teens) during young adulthood occurs in a significant portion of the young adult male population. Although it seems likely that females would be affected at approximately the same rate as males at this age if conditions were similar, males have been predominant in reported cases of adult myopia onset and progression. Much less information has been reported concerning females, although two studies with information on young adulthood changes in females were reviewed. One concluded that females are less likely to show myopic onset or increase after age 17, although it was noted that such findings could be biased by sex differences in culturally determined occupational patterns (Goss et al., 1985). The other study reported equal incidence of loss of unaided distance visual acuity among male and female college students (Parnell, 1951).

Progression studies must involve longitudinal evaluations of change in refractive status during or prior to young adulthood. Some studies make comparisons between subgroups, but most report results of two refractions of a selected group of subjects taken at intervals of two years or more. In many studies, all subjects have been engaged in common working or academic environments during the period between examinations.

JUVENILE MYOPIA

Even though we are interested primarily in myopia that is characterized by onset during late adolescence or early adulthood, some review of the most common form, appearing between the ages of 7 and 16, may add to our understanding about myopia with later onset.

Myopia that appears during childhood has been much studied since Cohn reported in 1867 its increasing prevalence with age. Cohn (1886) attributed the cause to intensive near-work demands in German gymnasia and implicated increased power of the crystalline lens. We now know that axial elongation is the mechanism primarily responsible (Baldwin et al., 1969; Fledelius, 1981b; Larsen, 1971d; Sorsby and Leary, 1970; Tokoro and Suzuki, 1968, 1969; Tokoro and Kabe, 1964, 1965). However, Cohn's findings of increased prevalence and progression during elementary and secondary school have been confirmed by studies in several countries throughout the intervening years (Baldwin, 1957; Banerjee, 1933; Blegvad, 1918; Bucklers, 1953; Conrad, 1874; Fledelius, 1981b; Goldschmidt, 1968; Hirsch,

1952; Kalogjera, 1979; Mantyjarvi, 1985b; Popov, 1931; Rosenberg and Goldschmidt, 1981; Saunders, 1986a; Sorsby and Leary, 1970).

Many cross-sectional studies of refractive status provide means of subgroups at various ages. Most show that the average value of refractive status ranges from +1.00 D. to +2.00 D. (under cycloplegia) before age 7. At approximately age 7, the mean refractive status begins to shift toward myopia and continues to do so until the late teens. It then remains essentially constant up to about 40 years, at which time a slight shift toward hyperopia begins. Beyond age 65 a slight shift back toward myopia is evident, at least in part due to nuclear sclerosis of the crystalline lens in approximately 10 percent of the elderly population who develop senile cataracts. Similarly, the decrease in mean refractive status during the period beginning at age 7 is produced not by a general decrease in refractive status but by the onset of myopia and its progression among a portion of the population. By age 25, from 15 to 25 percent of samples from clinic or general population groups have been found to be myopic by one or both of the following criteria: visual acuity is less than 20/20 and improved to 20/20 by concave lenses, or an amount of myopia of −0.50 D. or greater is manifested by objective or subjective measuring techniques.

Once myopia develops, it rarely decreases in magnitude prior to the onset of presbyopia. At approximately the same time as the development of presbyopia, decreases of small magnitude sometimes occur.

The question of whether refractive findings obtained under cycloplegia can be compared with those determined without cycloplegia has been addressed. Myopes less than 40 years of age show significant differences less often than do hyperopes. The effect is to increase slightly the average positive values of refraction in cycloplegic studies. Myopes show less mean change than do hyperopes. Therefore, prevalence figures of myopia or mean refractive states of myopes probably are not affected significantly by use of any cycloplegia. An exception to this is when atropine cycloplegia is used to produce complete paralysis of accommodation; in these rare studies, greater caution is required in comparing cycloplegic to noncycloplegic results.

The few longitudinal studies that have been conducted confirm the conclusion that from 15 to 25 percent of populations of children become 1 D. or more myopic between the ages of 7 and 13 rather than a smaller myopic shift occurring among a larger proportion. Many investigators have found that the earlier the onset of myopia, the higher the level at which it stabilizes (Bucklers, 1953; Fleischer, 1907; Norris, 1885; Rosenberg and Goldschmidt, 1981; Septon, 1984). Goss and Winkler (1983) and others (Baldwin, 1957; Brown, 1938; Brown and Kronfeld, 1938; Bucklers, 1953; Callan, 1875; Goss and Cox, 1985) have shown that myopic progression often slows during the early teens and typically stabilizes during the mid-teens. In a sample of 299 records of young clinic patients who were myopic, 75 percent of Goss and Winkler's male subjects showed no progression after age 17. Stabilization occurred a year earlier in the female sample, and 87 percent showed no progression after age 17. Saunders (1986b) performed cluster analysis on a longitudinal sample of young myopes and also found two distinct groups, but he found stabilization occurring over a wider age range: those who progressed after age 20 tended to continue to progress well into their 30s.

Nonmyopic children who are at risk of becoming myopic have been identified by various investigators as those who exhibit emmetropia or a very mild degree of hyperopia. Hyperopes above +1.50 D. rarely become myopic. Some investigators have found that they seldom become less hyperopic, and often become more severe hyperopes (Baldwin, 1957; Brown, 1936; Sorsby, 1933; Sorsby and Leary, 1970; Sourasky, 1928; Young, 1955). Data from military academy studies involve very low numbers of severe hyperopes, but at least

one study (O'Neal et al., 1987) suggests myopic shifts may occur in young adult students at least as often as among low hyperopes.

Socioeconomic, cultural, vocational, ethnic, and personality differences have often been found between children who have become myopic and those who have not (Baldwin, 1981). Many of these associations have been related to increased interest and activity in reading or other forms of near work or to greater success in these pursuits. While some association between juvenile-onset myopia and reading or academic achievement seems clear, there is little if any evidence to distinguish between cause and effect or whether these are commonly related to other variables.

Additional risk or associated factors for juvenile-onset myopia have been reported by several authors. Both heredity and culture have been implicated by theorists. Ocular predictors include esophoria (Goss, 1986b; Roberts and Banford, 1967) and against-the-rule astigmatism (Baldwin, 1957; Fulton et al., 1982; Kronfeld, 1930; Hirsch, 1964b). Premature birth has been implicated in all degrees of myopia (Fletcher and Brandon, 1955; Lledo, 1976; Scharf et al., 1975; Yamamoto et al., 1979). Higher prevalence of juvenile myopia has been found among those children who have suffered prior febrile disease (Hirsch, 1957; Sonder, 1920). Both dental caries (Goldstein et al., 1971; Hirsch and Levin, 1973; Keller, 1978) and malocclusion (Cattell, 1928; Manna and Mackiewicz, 1976) have been reported to be associated conditions. Incidence of myopia was found to increase among both children (Halasa and McLaren, 1964; McLaren, 1960) and adults (Livingston, 1946; Reed, 1947; Smith and Woodruff, 1951) suffering from severe malnutrition. This myopia may be reversible to some extent, suggesting a lenticular origin (McLaren, 1960). Children of myopic parents are likely to become myopic (Hirsch and Ditmars, 1969; Keller, 1973). It appears that there is a genetic factor, at least in the predisposition to become myopic, but neither its nature nor the degree of its influence has been established. It also appears that intensive near work sometimes produces a reversible form (accommodative or pseudomyopia) of low degree (Banerjee, 1933; Borghi and Rouse, 1985; Bothman, 1931; Conrad, 1874; Ebenholtz, 1986a; Hynes, 1956; Young et al., 1970). It is not known whether this can cause axial elongation and, thereby, permanent myopia.

YOUNG ADULT MYOPIA

Few existing reports provide data specifically directed at studying refractive changes among general populations from ages 16 to 30. We cannot extrapolate from cross-sectional studies to determine whether the slight decrease in annual means of refraction from ages 16 to 30 results in continuing progress in myopia among a smaller portion of teenage myopes or whether new myopes appear in significant numbers after the mid-teens. Studies that were reviewed support the conclusion that a number (perhaps 20 to 40 percent) of those college-bound individuals who are hyperopes of low degree or emmetropic before the late teens become myopes of low degree during this period or soon thereafter, and that a somewhat greater proportion of myopes become slightly more myopic (perhaps as many as 60 percent). Because these changes are small in degree, they have minimal influence on measures of central tendency. This is particularly true when samples include a broad age range. In this way a phenomenon of considerable import to those who determine eligibility criteria for admission to military academies is masked.

Groups of young males between ages 17 and 21 have been examined since 1876 to determine uncorrected visual acuity or refractive status prior to admission to college or military officer training, and again after a period of time. Studies of those ages 17 to 21 at entrance generally report that subjects exhibiting hyperopia of greater than +0.75 D. in the

TABLE 8 Percentage of U.S. Naval Academy Entrants Who Became Myopic, 1956

Sperical Equivalent Refraction at Entrance (Homatr 4.0%)	ages 17-18	age 19	age 20	age 21
+1.00 D. and above	1.5	1.5	2	3
+0.62 D. to +1.00 D.	11	8	4	2
+0.50 D. or less	69	56	33	10

SOURCE: Hynes (1956).

meridian of least hyperopia (perhaps as much as +1.25 D. if refraction is determined under cycloplegia) are unlikely to become myopic, even in those environments in which hyperopes of lower degree often become myopic, and in which myopes show progression. Myopes show myopic shifts approximately twice as often as low hyperopes, and mean magnitude of change is somewhat greater. More recently, young adult males from age 17 to the mid- to late 30s have been evaluated before beginning, and after exposure, to extensive near work in nonacademic settings. These are analyzed later again this chapter in the section on occupational studies.

Some studies show that subjects who are low hyperopes at age 17 are more likely to show changes than those who are older (see Table 8). Movement from low hyperopia into low myopia and myopic progression appears to be a more common phenomenon among young adults than traditionally assumed.

The following analysis of myopia onset and progression among young male adults is based on a review of the pertinent literature. In several instances, data from the original study could be reordered with respect to refractive categories or age ranges, thus permitting comparisons.

College Students

Unquestionably, many young adult males who undertake college study or assume roles that involve extensive near work become less hyperopic or more myopic. For very low hyperopes, the change may be great enough to produce a low degree of myopia. While many myopes also become more myopic, the former group represents a unique concern to those organizations that require unaided distance visual acuity of 20/20 or better at the end of training periods as well as at the beginning. At present, both the U.S. Air Force Academy and the U.S. Naval Academy enforce these requirements for those who would become pilots and naval line officers.

As noted earlier, U.S. military cadets have backgrounds similar in most respects to those who matriculate in U.S. colleges and universities (Houston, 1972). The only exception known to be related to myopia onset or progression is that most cadets were in the top 10 percent of their high school class scholastically, while few of the colleges and universities surveyed were this selective. The prevalence of myopia among cadets in the West Point studies

(Brown, 1986; Gmelin, 1976) was not significantly different from reports of prevalence among first-year students in other colleges.

Parnell (1951) classified 32 percent of first-year Oxford students as myopic. He then computed deterioration in distance visual acuity after one year for 150 male and 107 female students and found similar rates of deterioration in both sexes. Of those whom he originally classified as myopic, 13 percent showed deterioration of visual acuity within one year. As expected, there was no significant visual acuity loss among young hyperopes. Boynton (1936) found that 18.2 percent of college students had unaided visual acuity of 20/50 or less during the first year of study. At graduation, that figure had risen to 23.9 percent. Boynton noted that those with poorer acuity at entrance tended to change most and that better students tended to have poorer visual acuity. Luckeish and Moss (1939) found small decreases in myopia among students in grade school during summer vacation. They also reported a decrease in visual acuity for 21 percent of a class of U.S. college students during one academic year but noted that unaided distance visual acuity improved for many during summer vacation (Luckeish and Moss, 1940). Owens (1985) and Owens and Harris (1986) found a similar result with respect to 160 college freshmen tested at the end of summer vacation; after measuring myopic shifts during the academic year, individual refractive states changed again toward the refractive error at entrance by the end of the summer vacation period. These studies suggest pseudomyopia (i.e., incomplete relaxation of accommodation) as the basis for some of the visual acuity loss.

Most other studies that report increase in myopia among students during the first four years of college are cross-sectional and do not reflect selective withdrawal of students from the sample. The increased prevalence among graduate students shown in Tables 6 and 7 may reflect this selection factor as well as that of myopic onset during collegiate years.

Three studies of graduate students provide longitudinal data. Zadnik and Mutti (1987) found that 47 percent of a sample of 87 myopic law students showed a myopic shift of −0.50 D. or more between examinations conducted at various intervals during a three-year period. Riffenburgh (1965) selected three subjects from a population of graduate students and six others who began occupations that involved intensive near work who were not myopic at age 20 but who developed myopia. Mean change was estimated to be from −0.75 D. to −1.50 D. per year over a period of two to five years. Riffenburgh reports having seen several patients in whom "mild near sightedness that had not progressed after the age of 15 years suddenly began to increase again in the 20's, associated at this time with demanding near work." Schell et al. (1986) reported a myopic shift of −0.50 D. or greater in 30 percent of two successive classes of optometry students. Of this group of 109 subjects, 81 percent were myopic at entrance; their mean age was 25.

Occupational Studies

Longitudinal studies of the effect of length of time spent in a targeted activity range from 1 to 17 years' duration beginning with young adults. Cross-sectional studies suggest that greater mean rates of change occur during early periods because mean rates of change decrease after the early 20s. Data suggest that the total amount of myopia that develops among those who were emmetropes or low hyperopes before entering environments associated with risk seldom exceeds −1.00 D., and that when myopia progresses in these environments, the progression is seldom as much as −2.00 D.

A few longitudinal studies involving small numbers show that individuals may change at a fairly constant rate over several years, even into their 30s (Diamond, 1957; Kent, 1963; Kinney et al., 1979; Provines et al. 1983; Riffenburgh, 1965).

TABLE 9 Hyperopic U.S. Air Force Pilots and Navigators Who Became Myopic, 1983 (percentage)

Elapsed Time (years)	Pilots	Navigators
1-5	2.4	7.8
6-10	7.4	10.4
11-15	10.4	22.6
16-20	17.6	24.7
Total	7.8	13.6

SOURCE: Provines et al. (1983).

Studies of incidence must be longitudinal to distinguish between nonmyopes who become myopic and myopes who progress. From this point only longitudinal studies are referenced in which all members of a group have been exposed to a common environment. The studies examined are those in which individuals are tested before and after prolonged exposure to heavy reading demand or to a restricted work environment. Studies that include determination of visual acuity and refractive change show a very high correlation between the two; reports that assess visual acuity deterioration can therefore be compared with those that measure only refractive change, as far as onset of myopia or its progression is concerned.

Provines et al. (1983) compared myopic changes among U.S. Air Force pilots with those of navigators. Both were ages 20-25 when initial refractive data were collected; second records were obtained 1 to 20 years later. Table 9 indicates that a higher percentage of navigators became myopic at all elapsed time intervals after initial examination. Comparison of Provines' data can also be made with those of two U.S. Air Force Academy classes (Goodson, 1983; O'Neal et al., 1986, 1987). Table 10 shows the data for O'Neal (1986). Virtually none of those exhibiting hyperopia of +1.00 D. or greater at first encounter became myopic, although a high proportion shifted in the myopic direction. A significant number of those near emmetropia become −0.50 D. or more myopic.

Others report myopia developing and progressing among individuals in this age range. For example, Diamond (1957) found that, over 5 to 17 years, 24 percent of the 67 pilots studied became myopic after age 21. No myopia occurred for clinically significant amounts of hyperopia. All who became myopic (−0.25 D. to −1.25 D. spherical equivalent) were emmetropes or very low hyperopes between ages 21 and 31. Kent (1963) found similar changes in a small sample of naval officers.

Kinney et al. (1980) compared refractive changes of naval submarine crew members with those of National Guardsmen over a 3-5-year period. Subjects ranged in age from 18 to 41: 51 percent of the submariners showed unaided visual acuity loss versus 20 percent of the control group. Greene (1970) found that servicemen (all were college graduates) confined within ballistic missile sites tended to become myopic or increase in myopia. The mean change for those showing myopic shift over a four-year period was approximately −0.65 D.

TABLE 10 Myopic Shift After 2.5 Years in the U.S. Air Force Academy Class of 1985

Spherical Equivalent Refraction At Entrance	Total Number (Eyes)	Mean Change	Standard Deviation	Percentage Myopic Shifting -.25 or more	Percentage Shifting -.75 or more
+1.00 and above	35	-0.37	±0.51	65.7	20.0
+.25 to +.87	336	-0.16	±0.34	45.8	7.3
+.12 to -.12	184	-0.21	±0.45	41.3	14.7
-.25 to -.87	192	-0.38	±0.48	68.2	22.6
-1.00 and above	247	-0.70	±0.70	77.8	48.4

SOURCE: Calculated from O'Neal et al. (1986).

U.S. Military Cadets

Taken together, studies of cadets at U.S. military academies provide convincing evidence that about one in five young emmetropes and low hyperopes become low myopes in an intense academic environment and that more than half of all myopes, most of whose myopia has stabilized, under the same circumstances will show myopia progression.

That significant myopic shifts occur commonly among military cadets and consequently lead to visual disqualifications was first documented in the early 1940s. Hayden (1941) was the first to report myopic changes among midshipmen. His findings led him to recommend specific refractive error limits for entrance to the Naval Academy. From 1934 to 1940, unaided visual acuity dropped below 20/20 over the four-year training period for 21 percent of all graduates. On the basis of Peters's (1961) evaluation of visual acuity and myopia, we can assume that virtually all these changes in visual acuity were due to refractive shift into myopia. Hayden compared atropine cycloplegia at entrance examinations to homatropine cycloplegia: 65 percent of the 127 subjects found to be myopic under homatropine had been hyperopic under atropine when admitted. Almost half became visually disqualified within three years, while only 7 percent of those meeting the entrance standard of no myopia in any principal meridian under homatropine (4 percent) became visually disqualified during this period. Hayden reported that "the vast majority of candidates whose refraction was of the plano type, or +0.25 D. of hypermetropia, on their entrance examinations and some who showed +0.50 D. of hypermetropia at this time and were therefore physically qualified for admission were found to be physically disqualified because of defective vision (less than 20/20 in each eye) within one or two years after admission to the Naval Academy." He reported that all had become myopic and recommended that at least +1.00 D. of hyperopia be required for admission to the Naval Academy.

But how would such refractive constraints on admittees affect the eligible pool of candidates for the military academies? On the basis of Betsch's (1929) large sample of adults, approximately 20 percent would remain eligible by this criterion. In the Betsch

sample, less than 10 percent were −1.00 D. or more myopic. It is possible that hyperopes of this degree are underrepresented in this clinical sample, but Betsch and others have reported that there is no significant difference in prevalence at this and other refractive intervals between clinical and general populations. For example, Bennett and Rabbetts (1984) found 20 percent of spectacle prescriptions, among those receiving free eye care services in England, were from +1.12 to +2.00 D. (this is the range for hyperopes likely be admitted to the Naval Academy). Moreover, Brown and Kronfeld's (1929) sample exhibited 10 percent prevalence of hyperopia +1.25 D. or above under atropine. Therefore the figure of 10 to 20 percent eligible based on prevalence figures for a general population appears valid. However, although no studies reveal the prevalence of hyperopia +1.25 D. or above for young adults who could qualify for military cadet training, studies do show the prevalence of myopia among this group to be much greater than that found for young adult populations that include nonstudents and individuals who were not college bound. In a study of refractive errors among 836 entering West Point cadets, Brown (1986) found only 7 (less than 1 percent) who were +1.00 D. hyperopic or above, while 286 (34 percent) were myopic greater than −1.00 D. Gmelin (1976) found 0.05 percent cadets in the 1970 entering class were +1.00 D. or more hyperopic, while 44 percent were −1.00 D. or more myopic. West Point admission requirements include allowable refractive errors of ±5.50 D. Biederman has estimated that the proportion of eligible males of +1.00 D. or greater may be as low as 1 percent of the population of 18-year-old males (personal communication, I. Beiderman, Department of Psychology, University of Minnesota).

Of those eligible, based on a proposed spherical equivalent of hyperopic refractive error at entrance, what percentage could be expected to meet visual acuity standards upon graduation? Hynes (1956), in a study of the 1949 and 1950 graduating classes at the U.S. Naval Academy, found that 18 percent who had met unaided visual acuity requirements at entrance failed at graduation. He reported that a significant proportion of the acuity loss was due to development of myopia, older candidates reportedly being less likely to become myopic. Table 11 is a compilation from Hynes's data. Visual acuity data and refractions (retinoscopy under homatropine) were conducted under similar conditions at initial and final test periods. Hynes concluded that, if cycloplegic testing reveals hyperopia above +0.50 D., the attrition from onset of myopia would be less than 10 percent.

What are the risk factors for the rate of progression of myopia? Shotwell (1981) conducted an investigation of myopia among Naval Academy students that suggested that those who spend more time reading, as opposed to outdoor activities, are more likely to show myopic onset and progression. However, he was unable to demonstrate any preventive effect in a study of the influence of convex reading lenses (Shotwell, 1984).

The Naval Academy studies show that those who initially exhibit 20/20 visual acuity, but who develop myopia of low degree when placed in the Academy environment, have two characteristics in common: they are more often at or near the lower end of the age spectrum (age 17 to 21 at entrance) and most are essentially emmetropic (range from +0.50 D. to −0.50 D. in at least one (often all) principal refractive meridians) rather than hyperopic at entrance. These studies also indicate that the myopia that develops is of low degree, and that many hyperopes above +0.50 D. may have a similar shift in refractive error, which results in a lowering of their hyperopia, at least for hyperopes up to +1.00 D. For hyperopes of higher refractive error, there is some evidence that they tend not to show decreases at this age (Baldwin, 1957; Bucklers, 1953; Sorsby, 1933; Sorsby et al., 1955).

By the 1950s, the military academies had begun to tolerate refractive errors and uncorrected visual acuity less than 20/20. Beginning in 1960 the U.S. Military Academy at West Point instituted liberal admission policies with respect to refractive errors. Since that

TABLE 11 Refractive Error Change of 244 U.S. Naval Academy Graduates Who Retained 20/20 Acuity

Spherical Equivalent Refraction	At Entrance		At Graduation	
	N	Percent	N	Percent
+1.00D and above	138	56	46	19
+.62D to +1.00D	94	39	112	46
+.50D and less	12	5	86	35
Total	244	100	244	100

SOURCE: Hynes (1956).

time there have been a few studies of cadets, which compare refractive error at entrance to that at graduation. Sutton and Ditmars (1970) reported that, from 1964 to 1968, 45 to 51 percent of entering classes were myopic based on the criterion that concave corrective lenses were required to improve visual acuity to 20/20. Based on the number of hyperopic corrections worn, their magnitude, and uncorrected visual acuity expected of hyperopes, this criterion would not lead to overrepresentation of myopia by more than 2 percent. At graduation the number of nonmyopes (by this criterion) who became myopic increased by an average of 15 percent for the four classes. It is probable that almost all visual acuity loss was due to a shift from emmetropia or low hyperopia into myopia. As a point of reference, 33 percent of the total Army active duty personnel at about that time wore corrective lenses to achieve visual acuity of 20/20 (Rengstorff, 1972). Sutton and Ditmars also note that more than half of the admittees ranked academically in the top 10 percent of their high school classes and 80 percent won varsity letters.

Gmelin (1976) compared refractive findings in the U.S. Military Academy class of 1974 at entrance and after four years: 67 percent wore spectacles or contact lenses at graduation; 28 percent of those who were from +0.50 D. to +1.50 D. hyperopic became sufficiently less hyperopic to be placed in a lower refractive category at graduation. If we assume that all changes in category were toward myopia and were 1 D. or less, then 20 percent of emmetropes became myopic (−0.50 D. to −1.50 D.). This is confirmed by the author's report that the number of nonmyopes who become myopic was 81 (22 percent). This slight increase would be expected because a few hyperopes above +0.50 D. become myopic (Hynes in 1956 found 7 percent). This confirmation helps us interpret refractive changes in studies that merely report difference in numbers at various refractive ranges with time.

Brown (1986) compared the (noncycloplegic) refractive status of 418 West Point cadets determined prior to admission in 1975 and at the beginning of their senior year. A total of 418 subjects were randomly selected from the fourth-year class, and spherical equivalents were determined. The mean myopic change for the group was −0.66 D. Brown reported that the mean change of five subgroups, all of whom were myopic at entrance (entering spherical equivalent refractive errors of −0.50 D. to −6.50 D.); the amount of mean myopic change was similar for each group (see Table 12).

TABLE 12 Mean Refractive Error Change of U.S. Military Academy Seniors Who Were Myopic at Entry

Mean Spherical Equivalence at Entrance	Myopic Change
-.50 D.	-.71 D.
-1.50 D.	-.67 D.
-2.50 D.	-.67 D.
-3.50 D.	-.78 D.
-4.50 D.	-.67 D.
-5.50 D.	-.57 D.
-6.50 D.	-.63 D.

SOURCE: Brown (1986).

An unpublished study of the U.S. Air Force Academy graduating class of 1980 (Goodson, 1983) and a recent published technical report on the U.S. Air Force Academy class of 1985 (O'Neal et al., 1986, 1987) provide refractive error data that permit some comparisons. Both classes showed similar percentages of entering myopes, both with a myopic change after two or three years of −0.50 D. or more (57 percent) and with a change of −1.00 D. or more (25 percent). The percentage of entering hyperopes, emmetropes, and myopes with no shift or a hyperopic or myopic shift of 0.25 D. or more is shown in Figure 1 for the 1985 group.

For the entering emmetropes and hyperopes as a group, approximately 30 percent in both classes showed a negative change that resulted in a spherical equivalent myopia of no greater than −0.25 D. However, data forthis refractive group derived from the 1980 class show a more marked trend towards myopia of −0.50 D. or more at the second examination (43 percent) than for the 1985 class (15 percent). A myopic change of −1.00 D. or more was seen in 30 percent of the 1980 group of emmetropes and hyperopes, while only 6 percent of the 1985 group showed change of this degree. For the +0.75 to +1.50 D. hyperopes, a myopic change of −1.00 D. or more occurred in 43 percent (21) of the 1980 group, while only 2.5 percent of the 1985 group changed by this amount. The possible factors accounting for these differences in refractive error changes are the size and selectivity of the 1980 sample, and the added year in the academic environment in the Goodson study. In the 1980 class there were only 65 subjects in the group of emmetropes and hyperopes; in the 1985 group there were 245 emmetropes and hyperopes.

O'Neal gives more detailed changes for specific ranges of entering refractive error. The mean refractive error change over the 2.5 year period in the O'Neal study is given in Table 10 for various levels of entering refractive error. This table also shows the percentage of eyes at each refractive error level that showed a myopic change of −0.25 D. or more, −0.50

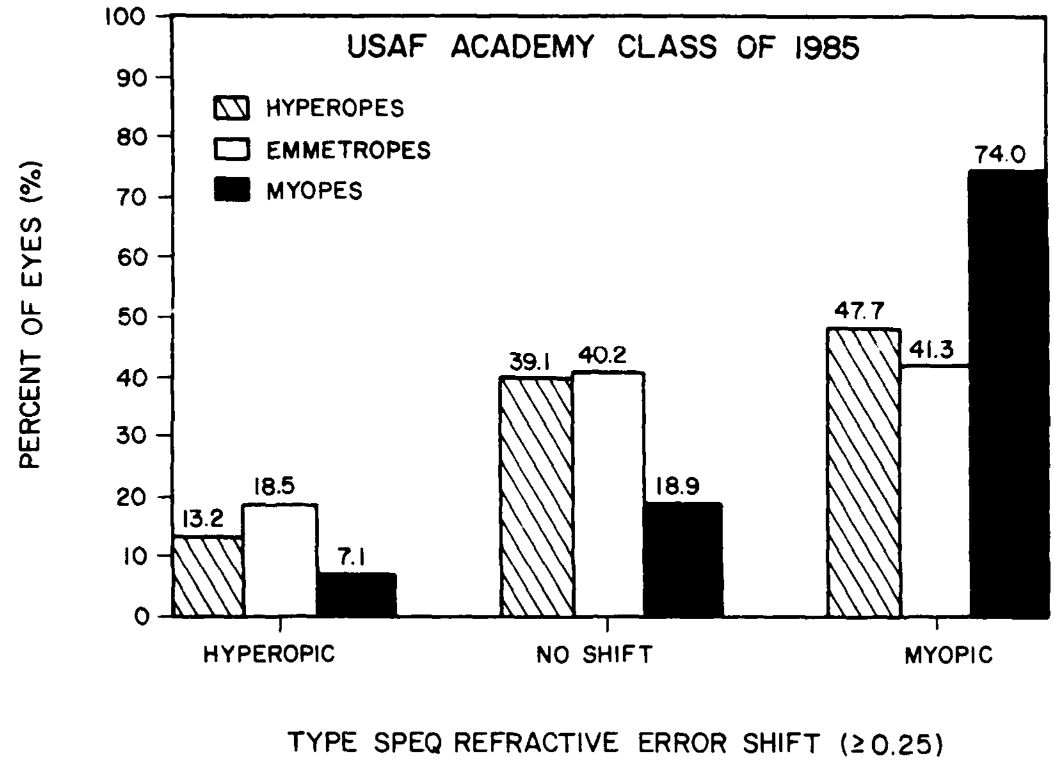

FIGURE 1 Mean myopic shift in spherical equivalent (SPEQ) refractive error between the entrance and third academic year exams (2.5 year period) for 664 eyes from the U.S. Air Force Academy class of 1985.

Source: O'Neal et al., 1986.

D. or more, and of −0.75 D. or more. Figure 2 shows that a larger proportion of myopic eyes shift toward greater myopia at all initial levels of myopia than do low hyperopic eyes. This figure also shows that the greater the initial myopia, the greater the myopic change is likely to be.

A more meaningful description of the refractive error change is obtained by analysis of the myopic change data separately. Goodson's three-year data show that 16 percent of the myopic shifts were −1.50 D. or more, but the numbers were small: 5 of 40 hyperopes, 5 of 24 emmetropes, and 21 of 132 myopes. In O'Neal's study, only 7.5 percent of the myopic shifts were −1.50 D. or greater: 4 of 209 hyperopes, 3 of 99 emmetropes, and 43 of 356 myopes. In O'Neal's study, the highest myopic shift was −1.75 D. for the entering hyperopes or emmetropes and −3.00 D. for the entering myopes. The mean myopic shift of only those eyes showing a myopic change was −0.83 D. after three years for the 1980 group and −0.60 D. after two years for the 1985 group. The mean myopic shift by level of entering refractive error is shown in Figure 3. The mean myopic shift was similar (−0.50 D.) for the hyperopes, emmetropes, and very low myopes and was about double (−0.80 to −1.00 D.) for the −1.00 D. myopes and above.

The higher amount of myopic change noted for the 1980 data than the 1985 study may be accounted for by the decision in the 1980 study to use only the data from the eye with the poorer uncorrected acuity. In addition, the 1980 study excluded a large number of subjects because the entering refractive data were not available for most of those who had 20/20 or better uncorrected visual acuity and did not wear spectacles. By 1985 refractive

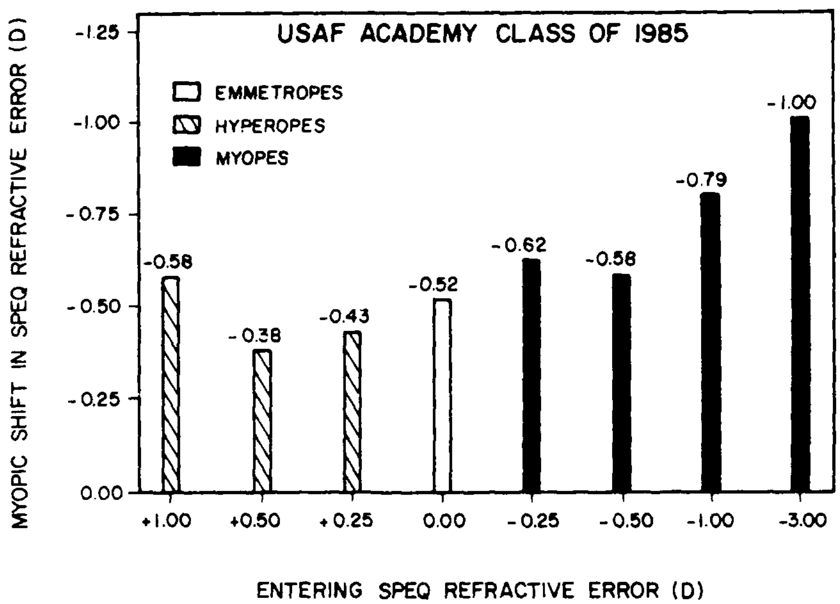

FIGURE 2 Percentage of eyes in selected ranges of entering spherical equivalent (SPEQ) refractive error with a myopic shift in SPEQ greater than or equal to amounts shown for 994 eyes from the U.S. Air Force Academy class of 1985.

Source: O'Neal et al., 1986.

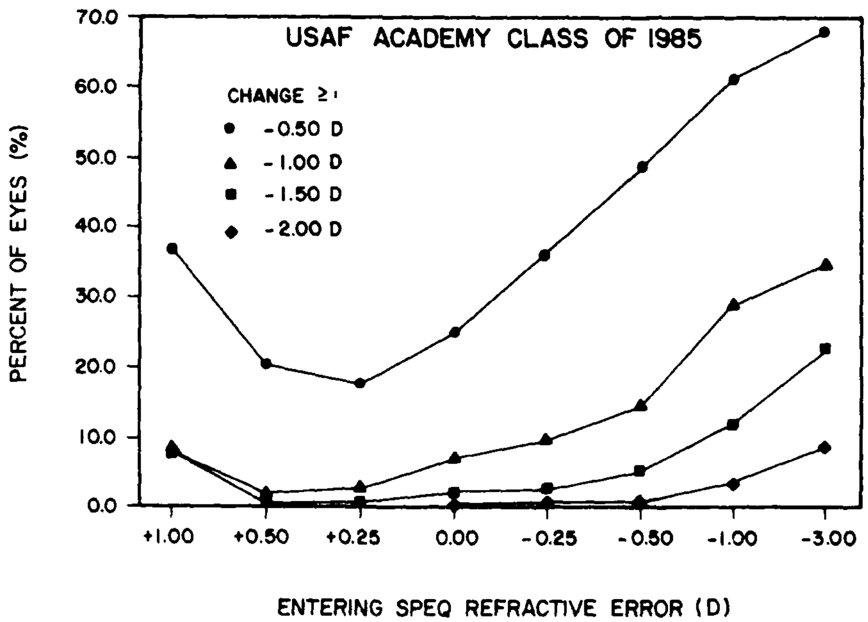

FIGURE 3 Percentage eyes in each type of entering spherical equivalent (SPEQ) refractive error showing either a 0.25 D hyperopic or myopic shift or no shift in SPEQ between the entrance and third academic year exams (2.5 year period) for 994 eyes from the U.S. Air Force Academy class of 1985.

Source: O'Neal et al., 1986.

error findings were required on all records; consequently, a similar bias did not exist in the O'Neal study. It should be noted that the 1985 study excluded those wearing contact lenses or near-vision glasses in order to eliminate the effect of these devices on refractive changes from the findings. This bias could be expected to diminish against the inclusion of myopes, since most contact lens wearers are myopic. In addition, all refractive error measures made after entering the academy were cycloplegic refractions.

Unfortunately, the military academy studies are often subject to additional biases that make interpretation of progression data difficult. For example, prior to entry into military academies, candidates receive refractive examinations from family doctors (optometrists and ophthalmologists), some of whom might be expected to empathize with applicants and underestimate the presence of myopia. Candidates with hyperopia are also more likely to be identified as emmetropic, since cycloplegic refractions are not routine prior to entry into the academies. To the extent that this is true, myopic shifts would be underestimated in hyperopia and overestimated for myopia.

CHANGES IN THE OPTICAL COMPONENTS OF THE EYE

The mechanism that produces myopic onset or increase in young adults is unclear. Goss and Erikson (1987) and Kent (1963) found steeper corneas after myopic progression in young adults. Adams (1987) found that axial length change explained all of his own adult onset-myopia. Schell et al. (1986) reported that most adult myopic shifts found in a group of optometry students were accounted for by axial elongation. McBrien (1986) found that axial elongation accounted for myopic changes in his young adult sample. Change in accommodative tonus (also called dark focus or resting level of accommodation) between the light-adapted eye fixating a distance target and in total darkness has been implicated by some investigators. Owens and Harris (1986) reported that noncycloplegic refractions taken at the beginning and the end of each of two freshman semesters exhibited significant myopic shifts, as did accommodative focus measured in darkness (dark focus). Ebenholtz (1986b) found differences between hyperopes and myopes with respect to dark focus: hyperopes showed less mean difference when compared to myopes, while, after sustained near work, dark focus decreased in hyperopes and increased in myopes. McBrien and Millodot (1987) found that after sustained near work, dark focus increased in late-onset myopes; emmetropes and early-onset myopes showed no significant change in dark focus; and dark focus decreased in hyperopes. Ebenholtz (1983) raises the interesting thought that those individuals with consistent hysteresis effects may have a higher risk for myopia and proposes that this hypothesis be studied.

4
Conclusions and Recommendations

An exhaustive review of the relevant literature uncovered no experiment specifically designed to answer the questions within our charge. Consequently, most of our conclusions are necessarily tentative and inferred from considering multiple studies, each with different purposes. Very few of the reports cited resulted from investigations undertaken to test a hypothesis. Many authors drew from existing data collections or compared their own data with those that had been assimilated by others for a different purpose and that employed different criteria. In short, it is difficult to interpret the relevant studies. Consequently, the most useful application of our efforts was considered to be the formulation of appropriate hypotheses and suggested guidelines for future research. What is needed is considerably more research targeted to answer specific questions, designed so that results of different investigators can be compared and so that relatively small numbers of cohorts can be studied over an extended time. In this section we offer our conclusions and recommendations, although they are necessarily inferential and tentative for the reasons stated above.

CONCLUSIONS

1. From 1812 to the present, studies of prevalence of myopia among college students and young adult males who entered military officer training indicate that myopia is much more prevalent among these groups at entrance than among other populations at similar ages.

2. Studies of the prevalence of myopia during the past 100 years lead us to conclude that, among Caucasian populations, there has been no major change in the prevalence of myopia within selected populations of schoolchildren and college-eligible young adults. An exception to this finding is that severe myopia appears to be less prevalent now at all ages.

This conclusion presumes that, even though it is impossible to directly compare data from the studies available to us because of the variations that have been enumerated, a significant trend probably would have been recognizable. Changes such as the proportion of the general population falling within specified age ranges and the possible short-term variations in risk factors could easily account for the magnitudes of difference in prevalence extrapolated from the literature. By comparison, it is possible that significant changes in prevalence of low and moderate myopia have occurred within certain other non-Caucasian ethnic groups (notably Eskimos and Japanese) or in some very local regions.

However, the proportion of the adult population attending college has changed markedly in the last 50-60 years: less than 8 percent of the adult population had attended college in the 1920s, whereas a comparable figure for the 1970s was 35 percent. Surprisingly, while myopia prevalence remains considerably higher in college students than noncollege students and about five times as many individuals attend college as did in the 1920s, the limited adult population studies fail to reveal significant changes in the prevalence of myopia. We find no clear and single explanation, but it may be that, while college attendance has changed, there has been a less dramatic change in the amount of intensive near work for the entire population. (Unfortunately, good noncollege myopia prevalence data are not available.) Alternatively, myopic changes in the college years may be small and transient for a significant number of individuals and therefore fail to affect adult population prevalence studies, which include a large proportion of individuals beyond college age. Finally, the imprecision of the data used for comparison in the two periods, perhaps combined with the above factors, does not allow for real changes to be identified.

3. Myopia most often develops and progresses between the ages of 7 and 16 years, then stabilizes in the late teens. Cross-sectional refractive data for individuals beyond age 16 suggest that onset and increase of myopia after that age occurs, although it is smaller in degree and appears limited to a subgroup. The degree of myopic shift among young adults is small enough to mask myopic onset or myopic change in the general population determined by cross-sectional studies. The possibility that the shift is not permanent and the fact that it does not occur in a large percentage of the general population would also tend to mask the change in cross-sectional studies.

The traditional view is that myopia onset or progression rarely occurs among young adults. Because available studies are limited to highly selected samples, we cannot assess general trends concerning onset or increase during young adulthood of myopia acquired during earlier years, nor can we ascertain whether this group of young adults experienced a period during which their myopia was stable, then was reinitiated by the influence of some new endogenous or exogenous factor. However, it seems clear that progression among young adult myopes who enter an academic environment, while less in degree than among juvenile myopes, occurs with significant frequency. While some young adult myopes may progress because stabilization of juvenile myopia occurs at a later age, the frequency of progression among college students and military cadets is much greater than would be predicted by studies of the age at which juvenile myopia stabilizes (Goss and Winkler, 1983; Saunders, 1984, 1986b).

4. Studies of college students and longitudinal studies of young adult males who entered military officer training, which have been carried out over the last 100 years, show that incidence and progression of myopia increase with time spent in training environments.

There are too few data regarding randomly selected male populations to determine the incidence or prevalence of myopia onset or progression in young adults (that which has onset or increases between the ages of 17 and 35); however, it seems clear that myopia has much lower prevalence among young males who do not pursue academic study or engage in extensive near work. They also appear less likely to develop myopia.

5. Based on all studies reviewed, we estimate that, from populations in which selected college and special near-work groups have been excluded, less than 10 percent of emmetropes and low hyperopes will develop myopia prior to becoming presbyopic. By comparison, as many as 20 to 40 percent of low hyperopes and emmetropes who enter colleges and

military academies or pursue occupations with extensive near-work requirements are likely to become myopic before the age of 25.

6. Prevalence of myopia has been positively related statistically to family income, level of education of parents, refractive status of parents, reading ability, and scholastic success.

It has been shown that applicants to West Point are similar in all these characteristics to applicants to universities who, like West Point matriculants, are in the upper 10 percent (scholastically) of their high school graduating classes (Houston, 1972). While we know of no study that specifically examines prevalence of myopia among high school graduates at this scholastic level, indications are that it is significantly greater than among the general population of similar age. The positive correlation between myopia and each of these other factors associated with successful application to colleges further reduces the applicant pool for military academies. While the direction of this influence is known, the magnitudes are not.

7. Some portion of young adult myopes progress after a period in which their myopia has become stable. Others without myopia develop it as young adults. Although available onset data are difficult to analyze, they generally indicate that shifts toward myopia among low hyperopes and emmetropes are less frequent and smaller in degree than among low and medium myopes.

Small measurement errors are more common in refraction of nonmyopes, especially when cycloplegic and drugless refractions are compared. These factors combine to make onset data unreliable. However, studies of uncorrected visual acuity loss indicate that at least 20 percent of nonmyopes become myopic during the four-year period following entrance to college or military academy. It appears that there is a distinct form of myopia (or myopic shift) for which young adults who enter academic environments are at risk.

8. It is not known whether any of those several predictors of juvenile myopia are also related to onset or progression of young adult myopia.

9. Virtually all students bound for military academies with noncycloplegic refractive errors at entrance of +1.00 D. or more in any principal meridian retain uncorrected visual acuity of 20/20 or better in each eye at the end of four years of study. However, if this criterion were to be used as a pass-fail basis for selecting military academy applicants, it would provide an unrealistic constraint on the eligible pool.

This conclusion can be understood in terms of the following analysis, which does not include an estimate for the increasing but still limited number of female applicants. There are fewer than 2 million 18-year-old males in the U.S. population. If we take an IQ cutoff for selection into the academies of one standard deviation above the mean (i.e., IQs of 115 or greater) as generally reflecting the intellectual capacities required to meet a demanding course of college instruction, then 16 percent of the general population, 320,000 males, will be eligible for consideration. Individuals in the Hayden (1941), Goodson (1983), and O'Neal (1986) studies with refractive status between −0.25 D. and +0.50 D. had a 0.75 probability of becoming myopic at −0.50 D. or more. The proportion of individuals with refractive status of +1.00 D. or more in the relevant population (mainly bright 18-year-old males) will then determine the number of individuals who comprise the selection population. If this proportion is as low as 1 percent, then only 3,200 (1 percent of 320,000) individuals make

up the pool of potential fighter pilot candidates. Clearly this is an unrealistic constraint on the eligibility pool for fighter pilot candidates.

RECOMMENDATIONS

Based on the findings of this review the working group makes the following recommendations.

1. Investigations should be undertaken to determine what proportion of young adults eligible for military academies and pilot training are hyperopic and which low hyperopes and emmetropes exhibit myopic shifts after entering this environment.

Special attention should be given to those risk factors that have been associated with juvenile myopia. The fact that young adult low hyperopes and emmetropes often develop myopia of low magnitude, and the fact that young adult myopes more often than not show increases in myopia when subjected to intense near-work environments suggest that there may well be other initiating influences that are similar to those related to juvenile myopia. The fact that the magnitude of myopic change in young adults is less than that of most juveniles who become myopic may be related to maturation differences rather than to a different mechanism. Determining risk factors could help identify the approximately 20 percent or more of military cadets whose uncorrected visual acuity becomes worse than 20/20.

2. The military academies should consider the following four approaches to increasing the pool of potential pilots:

A. Reducing the uncorrected visual acuity requirements for entrance. This should be done in conjunction with developing a program that might make feasible the wearing of corrective lenses (or contact lenses) while piloting. We recognize that, under current practices, this may be unworkable and that this approach may require further advances in medical technology.

B. Reducing the academic requirements for entrance. A slight downward shift in the academic requirements of one-tenth of a standard deviation (equivalent to a drop of 1.5 IQ points) from 115 to 113.5 would result in a 16 percent increase in the eligible population.

C. Searching for prophylactic measures that would reduce the shift toward myopia in academy students whose refractive errors are less than +1.00 D.

D. Increasing the proportion of the target population that does apply to the academies, through a "talent identification" program. Healthy, young (e.g., 13-year-olds) bright males and females whose refractive status is +1.00 D. might be identified, counselled, and recruited toward careers as military pilots.

3. The professional tasks of military academy graduates should be studied to determine if differences in performance of critical tasks can be related to refractive state. If so, the extent to which wearing ophthalmic corrections affects job performance should also be studied.

Are the gains in requiring unaided visual acuity of 20/20 greater than if those who are likely to become low myopes (or indeed those who are already myopic) are admitted and wear ophthalmic corrections? One trend that bears on this question is the declining pool of high school graduates, projected to decrease 25 percent by 1993 to 2,378,000 from its peak of 3,154,000 in 1976.

4. The refractive status and changes in refraction of those who are high achievers in various academic activities should be compared with those who do not show significant myopic shift. Comparison of refractive error and refractive changes should also be made between high achievers and low achievers for various academic activities.

A specific issue raised but not resolved by this study is the nature of the relation between myopia and special aptitude for reading and other near tasks. It may be that one factor in the significant increase in number of myopes in collegiate and military graduating classes is an association of certain college aptitude characteristics and myopia.

5. It is important to know what anatomical or functional changes are responsible for young adult myopia. We therefore recommend that research be conducted to determine how each of the optical components of the eye contributes to refractive state and to refractive change.

If adult onset or progression of myopia is principally a result of increase in the length of the eye, as it is in juvenile myopia, does this involve a renewal of accelerated ocular growth past the age at which such growth has normally declined? Questions such as this could be answered by a longitudinal study of college students in which each of the relevant ocular optical components among those who showed myopic progression could be compared with those who did not. Hypotheses concerning appropriate preventive measures can be selected more rationally after we have learned more about the optical components of myopic change and its probable cause(s).

6. Military academies should collect information on standard refractive components of the eye affecting refractive error under controlled conditions. The necessary technology and human resources are at hand to resolve the issues concerning causes, progression, optical components, and consequences of adult-onset myopia. For example, excessive axial elongation of the eye can usually be detected ophthalmoscopically by the presence of conus (crescent) or supertraction formation at the optic nerve head. It is possible that as a result of careful longitudinal studies of fundus characteristics, early changes might identify those eyes at increased risk of undergoing future elongation. These measures need to be evaluated against suspected behavioral risk factors, such as reading.

Rather than compile a lengthy list of such investigations, we provide an example to illustrate. It has been shown (Betsch, 1929) that frequency of conus, an effect of axial elongation, increases consistently from none in hyperopes above + 1.00 D. to 100 percent in severe myopia (see Table 13). We now need to know which hyperopes will become myopic and which myopes will progress. The use of an automated refractor, ultrasound for axial length measures, and other automated instrumentation would add efficiency and reliability. Data should be collected at entrance and annually thereafter. Of particular interest is a test of the hypothesis that those individuals who had experienced a period of axial elongation of the eye during their early teens (whether or not it produced myopia) are those that are most at risk for subsequent axial elongation during their college years.

7. Study designs should be standardized so that the results of various investigators can be compared. The following initial suggestions for standardization are offered, more to focus discussion that will lead to consensus than to provide final solutions.

A. Information of greatest value will be yielded by longitudinal studies. The number of subjects required for most longitudinal studies is often not large; however, they do necessitate selecting from groups in which the subjects will remain for the required period of time and in which there is minimum attrition. Educational institutions within which the

TABLE 13 Percentage of Eyes Exhibiting Conus at Various Refractive Intervals

Refractive Status	Conus
Above +6.0D.	Less than 1.0%
0 to +6.0D.	Less than 2.0
-1.00	3.3
-2.00	16
-3.00	29
-4.00	50
-5.00	47
-6.00	70
-7.00	75
-8.00	80
-9.00	90
-10.00	85
-11.00 and above	100

SOURCE: Betsch (1929).

distribution of students approaches national norms for ethnicity and socioeconomic status should be sought. Patients at health maintenance organizations and academically related clinics, students, and military personnel are generally most accessible. Such groups can be compared to determine if they demonstrate differences in prevalence or progression.

B. Classifications of age and age intervals should be annual with age determined by nearest birthday until age 22, after which two-year intervals are recommended. Test periods suggested are semiannual or annual for studies up to three years' duration, annually or biannually for studies from 3 to 10 years' duration, and every two or four years for studies of longer duration at older ages.

C. No study of refractive states should include less than a subjective or objective measure of refraction, corneal curvatures (using a small mire keratometer), and axial length. Regardless of whether an automated refractor, retinoscopic, or subjective measure is used, the examiner should be formally trained and the examiner or interexaminer reliability determined. Both cycloplegic and noncycloplegic refraction should be determined.

D. It is important to collect as much of the following data as circumstances permit: anterior chamber depth, crystalline lens power, tonometry, and fundus photography. While spherical equivalents most often have been used in tabulating data, it is recommended that principal meridians nearest vertical and nearest horizontal be tabulated separately and both eyes separately. If full analysis is not to be considered, it is recommended that right eye meridians nearest horizontal be chosen.

E. Emmetropia should be classified in two ways: +0.25 to −0.25 D. inclusive and +0.75 to −0.75 D. inclusive. Proposed refractive categories are 0.50 D. intervals to +3.00 D. and -6.00 D.; 1.00 D. intervals to +6.00 and -10.00 D. Prevalence studies should include all those with refractive errors greater than +6.00 D. of one category and those with greater than -10.00 D. of another category. Unless designed to discover changes among very high ametropes, progression studies need not include high refractive errors but should specify whether they are included. Studies comparing refractive errors obtained by various methods would permit better analysis of myopia research generally; most important among these are automated instrumentation measured against retinoscopic and subjective methods, and selected cycloplegic techniques against noncycloplegic subjective methods.

F. A retinoscopic method described by Hirsch (1950) and a cycloplegic refraction method (e.g., Bannon, 1947) represent two highly reliable ways to determine refractive states. The range of difference on retests and by a different examiner was ± 0.25 D. by both methods. Unless such methods are followed and described, measurement errors can be expected to invalidate attempts to evaluate and classify refractive changes or differences of ±0.50 D. or less. It is recommended that the designation of emmetropia as ±0.25 D. be reserved for those studies that determine reliability to be at ±0.25 D. and that ±0.75 D. define emmetropia in all other instances.

Appendix A
The Biological Basis of Myopia

While our natural tendency is to identify deviations from emmetropia, including myopia and hyperopia, as disorders or biological mistakes, this view has certain hazards. Since there is a substantial variation in the axial lengths of eyes, as well as in their optical power, it is not surprising that in all species there is some variation in how well these parameters are matched optically, with the result that some eyes deviate from emmetropia in the myopic direction and others in the hyperopic direction. Relatively few eyes are precisely emmetropic by most precise dioptric measures. Another drawback of viewing ametropias as biological mistakes is that nearly all infants are born hyperopic, with large variability in refractive status.

As eyes grow, three changes occur: (1) they become less hyperopic or become myopic; (2) they become less variable in refraction, and the shape of the distribution of refraction changes so that most eyes become nearly emmetropic and fewer eyes moderately ametropic than expected by a Gaussian distribution; and (3) the distribution curve becomes leptokurtotic (peaked). Thus the problem in assessing the prevalence of myopia lies in first deciding how far from emmetropia an eye must be to be considered myopic. Distant visual acuity is lost in direct proportion to the degree of myopia. A value as small as −0.25 D. will cause a slight loss; by contrast, young hyperopes without significant astigmatism retain acuity for distant vision even with refractive error.

It is far from clear what developmental mechanisms are responsible for this "emmetropization" early in life. One possibility is that the eye or brain somehow can sense the direction and degree of ametropia and cause some component of the eye to grow in such a way that the eye becomes emmetropic. Alternatively, the eye may become more emmetropic simply because as it grows, its optical surfaces become less curved; consequently, optical power is reduced. As this reduction in total optical power occurs, any slight mismatch between optical power and axial length will also have a progressively small effect on refractive error; consequently, the degree of myopia or hyperopia will decrease.

Whatever the mechanism, it is clear that growth in the direction of myopia from an initially hyperopic state in the newborn is a normal biological phenomenon affecting most eyes. In cases of manifest myopia, what is abnormal is that the process does not stop at emmetropia and may even accelerate. It is now also clear that the amount of myopia is highly correlated with axial length of the eye and not at all correlated with the steepness of the corneal curvature.

Most myopia found in any adult population is the result of changes that occurred after

the age of 7 and before the age of 16. This is called adolescent or juvenile myopia. However it is beyond the scope of this report to evaluate in detail what factors in one's environment or experience might cause significant myopia to develop. While it seems plausible that the frequent onset of myopia during the early school years points to specific circumstances associated with school, such as reading, numerous other changes in growth and physiological function are occurring at this time. There is strong evidence that juvenile myopic shifts in males and females usually stabilize during the teens. Similarly, the more frequent occurrence of myopia in the children of myopes may point to similarities in the family environment or activities, as well as to a genetic component. These factors cannot easily be isolated.

More puzzling yet is the development of myopia in young adulthood (adult-onset myopia), when the eye has stopped growing. Since this myopia development is often associated with intense study, it may be that the activities related to studying stimulate the eye's growth sufficiently to cause renewed growth, even in mature eyes. In some of these cases the myopia may arise, not from a change in the structure of the eye, but from its maintaining a continuous state of accommodation (spasm or tonic accommodation). This condition (pseudomyopia) might be expected to be limited by the amplitude of accommodation and, consequently, be absent when individuals lose all their accommodation in presbyopia. At present, it is unclear whether changes leading to young adult myopia involve axial elongation, as in juvenile myopia, or whether other mechanisms are responsible.

So-called pathological myopia is not of direct interest to this report, since it occurs relatively infrequently and has no special predeliction to the young adult age group. Nevertheless, it is useful to understand that it is associated with pathological elongation of the anterior posterior axis. High levels of myopia frequently lead to blindness as a result of the rapidly increasing size of the posterior segment of the eye, causing degenerative changes in the retina (Curtin, 1985).

The pathophysiology of postnatal ocular expansion produces characteristic changes in the fundus appearance. The most common of these changes is crescent or conus formation. In this condition, a disparity exists between the areas of the overexpanded scleral shell and the retinal-choroid within. This disparity caused shifting of the choroid and retina temporally toward the side of the globe that is expanded most. This "temporal shear" results in a retraction of the lamina vitrea (Bruch's membrane) from the temporal margin of the optic nerve head, producing a crescentric area on the temporal aspect of the disk in which the lamina vitrea and its attached tissue, the choriocapillaris and the retinal pigment epithelium, are absent. As a result, the inner aspect of the sclera becomes exposed and imparts a white color to the crescent area viewed ophthalmoscopically. Supertraction is the converse of the traction that produces crescent formation. With temporal shearing of the choroid-retina upon the inner sclera, the optic nerve acts as a barrier to this process so that these inner ocular tissues become piled up and superimposed on the nasal margin of the optic nerve. An eye that presents with crescent formation, supertraction, or both has already expanded beyond its normal growth limit.

Even moderate levels of myopia may show some of these fundus signs and may be associated with a higher incidence of retinal detachment and certain other degenerative processes affecting the eye.

Appendix B
Review of the Prevalence Literature

Myopia prevalence refers to the proportion of individuals in a population who are myopic at a given time. Two major issues in measuring prevalence concern the ability to correctly classify individuals as myopic and nonmyopic and the manner in which the observed group was selected from the population at large. Classification criteria are described in Chapter 1, in the section on interpreting the myopia literature. Chapter 4 contains the working group's recommendations for classification standards for future studies.

AGE

In most populations, age is the most important determinant of the distribution of refractive error, at least during the first three decades of life. Prevalence studies necessarily take a cross-sectional view of the patterns of refraction in relation to age. The characteristics of this pattern depend on the longitudinal development of refraction within the population, secular trends in refraction, and selective (survival) factors operating from one age group to the next. If two of these are known or can be reasonably assumed, and if sampling is valid, then inferences about the third can usually be made from cross-sectional data. Age patterns of myopia prevalence seem to be used in two major areas of inquiry. The first concerns the progression of myopia and changes of refraction with age. An excellent example of this kind of interpretation of cross-sectional data is provided by Hirsch (1952) in a study of 9,552 schoolchildren, ages 5 to 14, in the vicinity of Los Angeles, California. In the context of universal education, one would expect little selection- or refraction-associated attrition in such a study. There is also little reason to expect a major secular trend over the 10 years separating the 5-year-olds from the 14-year-olds. This study uses a sophisticated statistical analysis that addresses the problems of making longitudinal inferences from cross-sectional data, presenting both means and centiles. The reporting of the percentage of students having various refractive states by age and by gender also makes possible the estimation of the prevalence of myopia based on various degrees of refractive error.

Kalogjera (1979) studied 483 children ages 3 to 7 in Central Zagreb, Yugoslavia. Examinations, consisting of skiascopy under cycloplegia, were done in connection with vaccinations. Refractive error was reported in 1.00 diopter (D.) intervals. About 3.4 percent of eyes had a negative refractive error of −1.00 D. or more. There was no apparent trend with age, but the numbers were small.

Hirsch (1952) found that the percentage of children with a negative refractive error

greater than −1.00 D. increased from 0.6 percent in 5- and 6-year-olds to 5.4 percent in 13- and 14-year-olds. The prevalence of any negative refractive error increased from 6.8 percent in 5- and 6-year-olds to 23.9 percent in 13- and 14-year-olds. Kempf et al. (1928) examined 1,860 Washington, D.C., schoolchildren in 1924. Refractive error was determined by retinoscopy under cycloplegia. The percentage of right eyes with a negative refractive error equal to or greater than −0.25 D. rose from 1.4 percent among 6- and 7-year-olds to 9.1 percent among 12- and 13-year-olds and also in those 14 years and older.

In Finland, Laatikainen and Erkkila (1980) studied 411 schoolchildren; 1.9 percent of 7- and 8-year-olds had a negative refractive error equal to or greater than −0.50 D., increasing to 21.8 percent among 14- and 15-year-olds.

Most studies of older children and young adults show a continued increase in the prevalence of myopia into the third decade. Johansen (1950) studied Danish students ages 12 to 15 and found an increased prevalence of myopia with increasing age. Goldschmidt (1968) studied Danish schoolchildren ages 13 to 14 and found that 9.7 percent had either a previously ascertained myopia, reduced visual acuity, or a school record of use of glasses accompanied by optimum vision achieved by spherical concave lenses in one or both eyes. Among military recruits ages 18 to 25, 14.5 percent wore glasses with a negative correction. The author concluded that about one-third of myopes become myopic after their fourteenth year. Fledelius (1983) studied patients referred for ophthalmological evaluation of general disease, excluding referrals for glasses prescriptions. Among nondiabetics, the highest prevalence occurred in the age group 26 to 35 .

Two surveys conducted by the U.S. government contain data on older children and young adults. Angle and Wissmann (1980a) reported on an analysis of data from the United States Public Health Service Health Examination Survey, cycle III, summarized originally by Roberts and Slaby (1974). They found a slight increase in the prevalence of myopia with age, from 29.9 percent at 12 to 33.2 percent at 17. Sperduto et al. (1983) analyzed a subset of the data in the National Health and Nutrition Examination Survey (NHANES) collected between 1971 and 1972 and reported by Roberts and Roland (1978). Although Sperduto et al. report little variation with age, the data show an increase in prevalence of myopia from 24 percent among 12- to 17-year-olds to 27.7 percent among 18- to 24-year-olds, followed by a drop to 24-25 percent in the older age groups. Whereas the differences may not be statistically significant, they are consistent with other observed age patterns.

Adults over age 40 were studied in Israel by Hyams et al. (1977). The study was done in conjunction with a glaucoma screening program, and refractive error was determined from the subjects' own glasses. This methodology was felt to be valid by the authors because of the availability and use of ocular care. The authors report no change in the prevalence of myopia from the age of 40 to age 70 and a decrease thereafter.

Many studies that report mean refraction other than prevalence suggest that the prevalence of myopia reaches a peak at about age 20 to 25, declines slightly to age 45, and then begins to rise very slightly again (Brown and Kronfeld, 1929; Jackson, 1932; Pendse and Bhave, 1954; Sorsby et al., 1960).

The pattern of marked increases in the prevalence of myopia during childhood largely reflects longitudinal growth patterns. Interpretations of the various patterns of plateau or decline after age 30 are discussed below in the section on secular trends. Whatever the source of the age- related patterns of myopia prevalence, it is clear that age must always be considered a potential confounder in comparisons of myopia prevalence between populations or subpopulation groups. This confounding could probably not be controlled by a single linear term in a regression model if the age range of subjects is very wide. By contrast,

populations of schoolchildren, a common source of data on myopia prevalence, may have similar numbers of children at all age levels, in which case there would be no confounding if the age range of the compared groups is the same. Controlling for age may also not control for age-associated phenomena, such as developmental maturation. Thus, differences between populations in childhood may not necessarily imply differences in the ultimate prevalence of myopia.

GENDER

The relationship of myopia prevalence with gender appears to be less consistent, less well documented, and less predictive than that with age.

Peckham et al. (1977) studied 11,179 children in England, Scotland, and Wales. There was no significant difference between the sexes in the occurrence of "acquired myopia," defined as poor distant vision, satisfactory near vision, and a deterioration of two lines in distant visual acuity in children between ages 7 and 11.

In California, Hirsch (1952) found a more negative (myopic) refraction among boys than among girls ages 5 to 6, shifting to more myopia among girls at age 13 to 14. The age pattern depends on the parameter of refraction being considered. For example, for myopia in excess of 1.00 D., the percentage of girls became slightly higher than the percentage of boys starting at age 7 to 8, markedly higher at 11 to 12, and only slightly higher again at 13 to 14. By contrast, both the mean and median refraction are higher (less myopic) for girls than for boys until ages 13 to 14. Hirsch attributes this pattern to the earlier onset of puberty in girls. Kempf et al. (1928) reported a slightly higher proportion of myopes among boys than among girls for all ages, including 14 and older. Angle and Wissmann (1980a), in their analysis of data from the 1966-1970 National Health Examination Survey, found a higher prevalence of myopia among females than males ages 12 to 17. Whether this varied with age is not stated. Sperduto et al. (1983) reanalyzed data on people ages 12 to 54 from the 1971-1972 National Health and Nutrition Examination Survey. They reported higher prevalences in women than men through ages 25 to 34.

Goldschmidt (1968) found a higher prevalence of myopia in girls than in boys among Danish schoolchildren ages 13 to 14 but cautions that this does not imply that females are in general more myopic, since these results may reflect differences in maturational development between boys and girls at that age. Krause et al. (1982) found a higher prevalence of both myopia and hyperopia in female than in male Finnish schoolchildren, on the basis of a questionnaire reporting ophthalmologist visits and records of refraction; they also pointed out the connection with puberty.

Studies of Eskimo and American Indian populations are also inconsistent in their gender patterns. Alsbirk (1979) reported a higher prevalence of any negative refractive error as well as a negative refractive error greater than −2.00 D. among men than among women over age 40; it was statistically significant for any negative refractive error. Myopia prevalence was somewhat higher for women than for men ages 15 to 39, but this was not statistically significant. Woodruff and Samek's (1977) data on Ontario Indian populations suggest more myopia among females, largely during adolescence. Among Belcher Island Eskimos, however, Woodruff and Samek (1976) report a lower mean refraction for males than for females. Since the standard deviation of refractive error is similar for males and females in this study and there are no high refractive errors, the prevalence of myopia is also probably higher in males, but this comparison may be confounded by age. Since participation rates for women tend to be higher than for men in these studies, observed gender differences may also be due to differences in selection.

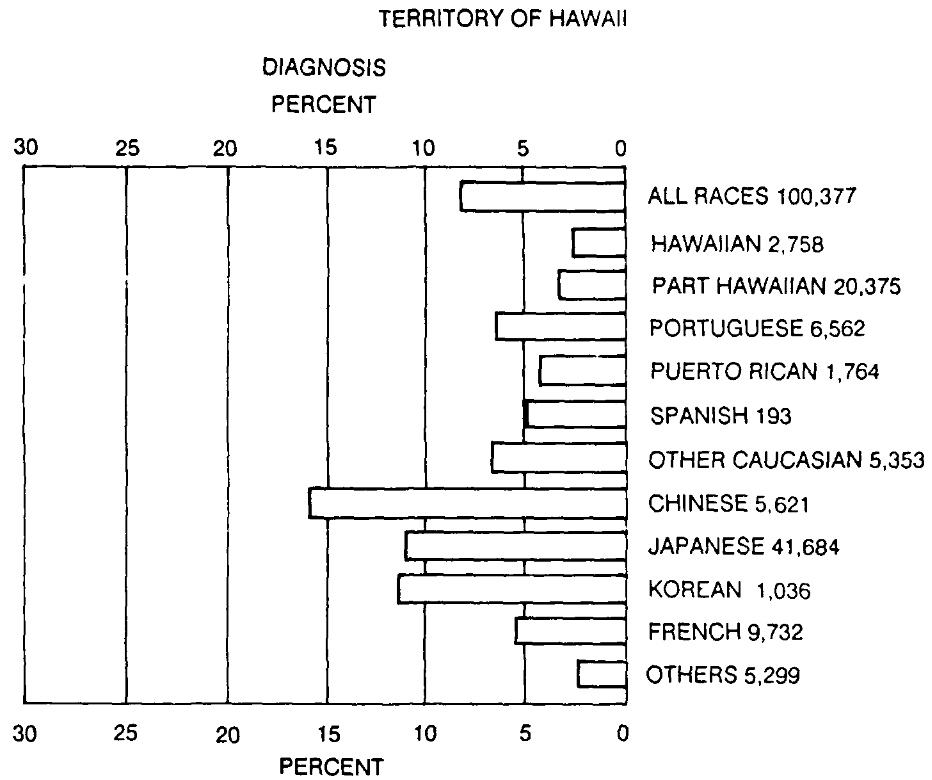

FIGURE B-1 Myopic errors by race. This figure represents eyes; in many individuals both eyes have the same defect, so the percentage on a case basis would be somewhat more than half of the figures given here.

Source: Adapted from Crawford and Hammond, 1949.

RACIAL AND ETHNIC PATTERNS

Asians

The original data from prevalence studies in Asian countries are not among the articles reviewed. Sato (1957) refers to prevalence rates as high as 67 percent among high school students in Japan. In Hawaii, Crawford and Hammond (1949) screened nearly 100,000 schoolchildren for a defect in vision or ocular balance. The classification of a student as myopic was based on the subsequently reported refractive error from an ophthalmologist or optometrist. As indicated by Figure B-1, myopia was found to be most common among the Chinese students, followed by Japanese and Korean students. Hawaiians, part-Hawaiians, and a group designated as "others" had the lowest prevalences of myopia.

Jews

Two studies comparing Jewish and non-Jewish subpopulations report more myopes among Jews. Kantor, summarized by Sorsby (1932), compared the prevalence of myopia among Jews and White Russians (Byelorussians). Among Jews the prevalence of myopia was 14.75 percent; among White Russians it was 4.93 percent; among the subgroups who worked as type compositors, the prevalence of myopia was 22.8 percent for Jews and 6.1

percent for White Russians. The methods for selecting the sample were not specified, nor were those for estimating myopia. In London, Sourasky (1928) studied Jewish and non-Jewish schoolchildren. Among boys ages 8 to 13, visual defects were more common in Jews than in non-Jews and unrelated to age. He also examined case records and found a higher proportion classified as myopes among Jews than among non-Jews.

In Israel, Hyams et al. (1977) studied men and women over 40, mostly of eastern European origin, in communal settlement. The prevalence of any negative error was found to be 18.4 percent, the prevalence of a negative error greater than −1.00 D. was 11.6 percent. These rates may be underestimates because of the use of subjects' glasses to determine refractive error. Shapiro et al. (1982a) reported on students ages 18 and 25 at the Hebrew University in Jerusalem. A negative refractive error of −0.25 D. or more in at least one eye was found in nearly 13 percent of those who had visited the university health service. There is, of course, concern that university students who register at the university health service may not be representative of the general student population and, furthermore, that prevalence of myopia in university students is likely to be higher than in the general population.

Taken together, these studies do not seem to provide strong evidence supporting the belief that myopia prevalence is unusually high among Jews. The values reported are not noticeably higher than reported values for other Caucasian adult populations, and the validity of the internal comparisons is uncertain.

Blacks

Two sets of data document a lower prevalence of myopia in blacks than in whites in the United States: the National Health Examination Survey of youths ages 12 to 17, reanalyzed by Angle and Wissmann (1980a), and the National Health and Nutrition Examination Survey, of which a subset ages 12 to 54 was reanalyzed by Sperduto et al. (1983).

The two reports from Africa that were reviewed had very different findings. Abiose et al. (1980) surveyed 5,220 postprimary schoolchildren (ages 12-20) in Kaduna, Nigeria, to determine the need for ocular care. Of the 5,220 children screened for visual acuity, visual defects, and any ocular pathology, 886 were referred for further examination, and 744 of these were actually examined. Of the 140 children who were refracted, the records of 127 were available for analysis, and among those 79 were found to be myopic: these 79 represent less than 2 percent of the original screenees. Even allowing for the possibility of missing many cases, and despite the absence of a clear criterion for myopia, this finding represents an unusually low prevalence for students ages 12 to 20. The authors' conclusion that myopia was common in this population is based on the proportion of myopia among students refracted.

McLaren (1960) reported on two surveys of related tribes conducted in Tanganyika, one near Mvumi and the other near Mwanza. One major difference between the two areas was that, whereas Mwanza had not recently experienced any serious food shortages, the area around Mvumi had experienced frequent famines, the last of which occurred about five years before the survey. Thus, the children of Mvumi were survivors of a time of nutritional deprivation. Refraction was determined by retinoscopy under cycloplegia and a mean of the four values (two horizontal and two vertical meridians) of the two eyes was calculated, from which 2.00 D. (1.00 D. for distance and 1.00 D. for cycloplegia) were subtracted. Estimating from a histogram of the refraction distribution, the proportion of children with a negative refractive error of −1.50 D. or more appears to be about 7 to 10 percent, somewhat higher among the Mvumi than the Mwanza. This probably corresponds

to myopia greater than −0.25 D. after readjusting for one of the corrections. These data, though difficult to compare with other studies in the absence of age-specific rates, do not suggest an extremely low prevalence of myopia in what was then Tanganyika.

American Indians

Three studies of the Americans Indians were reviewed. Jones (1908) reported on 289 Indians ages 14 to 22, from about two dozen different tribes who attended the Hampton Normal and Agricultural Institute. The criteria for myopia included visual acuity of less than 20/20 or symptoms accompanied by myopia diagnosed by refraction under cycloplegia. Myopia was found in 10 percent and astigmatism in 26 percent of eyes. Wick and Crane (1976) examined 398 Sioux schoolchildren in Grades 1 through 5. Retinoscopy was performed without cycloplegia, using a cartoon for fixation: 13 percent of the eyes were found to have a negative refractive error of −0.25 D. or more. In addition, high degrees of corneal astigmatism are reported. Heard et al. (1976) studied 420 Zuni schoolchildren in grades K through 12. Mean and median spherical refractive errors for the right eye based on retinoscopy were reported. The mean spherical refractive error was +0.87 D. in grade K through 6, and −0.62 D. in grades 7 to 10. There was no mention as to what, if any, means were used to relax accommodation. Wick and Crane concluded that mean refractive error is hyperopic compared with a study of Caucasian schoolchildren. However, there was no discussion of the comparability of these two studies. They also reported an unusually high degree of astigmatism. Overall, while these studies do not indicate a pattern of either very high or very low prevalence of myopia, they do suggest the possibility that astigmatism is unusually common among American Indians.

Australian Aborigines

Taylor (1980) studied visual acuity and the distribution of refractive errors in 161 Australian aborigines in eight communities and 152 Australians of European origin, 20 to 30 years of age. Approximately 4.8 percent of the aborigines had a negative refractive error greater than −0.75 D., compared with 13.5 percent of the Europeans; no aborigine had myopia of greater than −4.00 D. No mention was made of the level of literacy in either of the two groups; however, visual acuity was determined using an illiterate E chart. It was specified that the areas sampled had only recently come under European influence and that traditional values and lifestyles of the aborigines were maintained.

TIME TRENDS

Evidence about secular time trends of myopia prevalence is of two types: comparisons of myopia prevalence at two different times and inferences from the age patterns of myopia prevalence. Actual comparisons over time are limited by differences between studies in methods of measurement and the selection of study subjects. For example, Ask (1925) described a drop in the prevalence of myopia in Sweden from 1885 to 1920, which he attributed to changes in the school curriculum and "hygienic measures." However, there may also have been a change in the selective nature of the school population during that time.

Denmark

Table B-1 presents data regarding time trends in Danish schoolchildren ages 12 to 14.

TABLE B-1 Studies of Myopia Prevalence Among Danish Schoolchildren, 1884-1968

Study	Year	Number	Age (years)	Criterion (D.)	Class	Prevalence (%)
Bjerrum	1884	198	13-14	≥ -1.50	Normal school	10.6
Philipsen	1884	210	13-14	≥ -1.50	Normal school (advanced)	12.4
Johansen	1950	?	12-15 (boys)	> -0.50	Rural school	8.2
Goldschmidt	1962	9,243	13-14	≥ -1.50	All streams	6.0
Goldschmidt	1962	3,226	13-14	≥ -1.50	Academic stream	8.4
Goldschmidt	1962	486	13-14	≥ -1.50	Grammar school	10.7

In 1962, Goldschmidt (1968) surveyed 9,243 children born in 1948 who were residing in Copenhagen. The criteria for myopia included a previously ascertained myopia or reduced visual acuity or a school record of the use of glasses and, in addition, an examination in which the optimal visual acuity was achieved by use of spherical concave lenses in one or both eyes. By these criteria, 9.7 percent of students attending normal schools were found to be myopic. Goldschmidt compares his results with those of Bjerrum and Philipsen (1884), who report approximately 11.5 percent myopia among schoolchildren ages 13 and 14 in 1884. This is believed to correspond approximately to a myopia greater than 1.50 D. The prevalence of myopia of this degree in Goldschmidt's study was 6.2 percent. However, Goldschmidt felt that Bjerrum and Philipsen may have overestimated the prevalence of myopia, since 60 percent of their population came from "higher schools," probably resulting in an overrepresentation of the more academically oriented students. When these data from the earlier study are compared with the prevalence Goldschmidt found in academic classes (8.4 percent) and grammar schools (10.7 percent), there is much less discrepancy. Johansen (1950) studied boys ages 12 to 15 in seven schools outside Copenhagen. He found that 8.2 percent of boys exhibited a negative refractive error greater than or equal to −0.50 D. based on reduced visual acuity in either eye plus an "ordinary eye examination" for "simple myopia." These results are very close to the 8.5 percent myopia reported in boys by Goldschmidt.

TABLE B-2 Studies of Myopia Prevalence Among Danish Men, 1882-1983

	% Myopic
Military Recruits	
Tscherning (1882)[a]	8.3
Goldschmidt (1968)[b]	14.5
excluding refractive error of -1.5 D. or less	9.2
Referrals[c]	
Fledelius (1983) [d]: refractive error -0.25 D. or greater	32.6
excluding mild myopia	10.3

[a]Probably refractive error greater than 1.5 D.

[b]Ages 18-25; negative refractive error based on subjects' own glasses.

[c]Ages 16-25.

[d]Includes a high proportion of diabetics.

Table B-2 represents data on young men in Denmark. In 1964, Goldschmidt (1968) surveyed 3,651 Danish young men ages 18 to 25 who attended the medical board for conscription. Approximately 14.5 percent had a negative correction based on the refractive value from subject's own glasses. He compared these data with those reported by Tscherning (1882), who found a prevalence of myopia of 8.3 percent among military recruits in 1882, probably corresponding to a negative refractive error of at least −1.5 D. Upon excluding negative refractive errors of −1.5 D. or less, the prevalence of myopia among the 1964 recruits was 9.2 percent, and after stratification by occupational category, even this small difference disappeared.

Fledelius (1983) compared the data from his 16- to 25-year-old age group with those reported by Tscherning and Goldschmidt. His study population was comprised of referrals for ophthalmological evaluation of general disease (see methods above) and included females and a high proportion (20 percent) of diabetics. His reported prevalence of negative refractive error of greater than or equal to −0.25 D. was 32.6 percent (diabetics and nondiabetics combined). However, upon removal of lower degrees of myopia (degree not specified but probably a negative error smaller than −2.00 D.), the reported prevalence was 10.3 percent, a figure quite close to those of Tscherning and Goldschmidt.

United States

Table B-3 summarizes the four sets of data providing information regarding time trends in prevalence of myopia in the United States:

(1) A survey of Washington, D.C., schoolchildren ages 6 to 14 and over (Kempf et al., 1928).

(2) A survey of California schoolchildren ages 5 to 14 (Hirsch, 1952).

TABLE B-3 Myopia Prevalence Among Children and Adults in the United States, 1924-1972 (Percentage)

Age	Myopic Error (D.) Washington, D.C.[a] 1924 ≥-.25	≥1.0	>1.1	California[b] 1952 ≥-.12 D.	>-1.0 D.	Throughout U.S.[c] 1966-70 % eyes ≥ -.12D.	Throughout U.S.[d] 1971-72 (right eye) ≥ -.12D.
6							
7	2.1	1.2	0.9				
8				10.4	0.9		
9				16.4	1.9		
10	5.4	2.4	1.6				
11				21.2	4.4		
12						29.9	
13	9.1	3.9	3.2			31.5	
14				23.9	5.4	31.2	24.0
15						31.9	
16						33.0	
17						32.2	
18-24							27.7
25-34							24.

[a]Kempf et al. (1928).

[b]Hirsch (1952).

[c]Roberts and Slaby (1974); Angle and Wissmann (1980a).

[d]Roberts and Roland (1978); Sperduto et al. (1983).

(3) The 1966-1970 Health Examination Survey (HES) Cycle III of noninstitutionalized youths ages 12 to 17, reanalyzed by Angle and Wissmann (1980a).

(4) A subset ages 12 through 54 of the 1971-1972 National Health and Nutrition Examination Survey (NHANES), which was reanalyzed by Sperduto et al (1983).

Kempf et al. (1928) collected data on 1,860 Washington, D.C. schoolchildren in 1924. All the children were Caucasian and ranged in age from 6 to over 14 years. The measure of refractive error was based on retinoscopy under homatropine cycloplegia. In order to examine whether the requirement of parental permission for the administration of cycloplegia might have resulted in a selection bias, the authors compared the visual acuity of the children in the study with that of nearly 1,000 children in the same schools whose parents refused to permit the use of cycloplegia and with the visual acuity of groups of children tested in South Carolina, Maryland, Delaware, and New York. The distributions of visual acuity based on the Snellen eye chart were similar for all three groups. The paper presents extensive, detailed distributions, usually of the right eye alone or the right and left eye separately, of various measures, including visual acuity with and without cycloplegia, refractive errors in the vertical and horizontal axes, and astigmatism, using various criteria for classification. From these, the prevalence of myopia based on various criteria of refractive error can be estimated. Categories of refraction are designated by a single number at

quarter diopter intervals. The prevalence of negative refraction error of −0.25 D. or more and greater than −1.00 are presented in Table B-3.

Hirsch (1952) examined 9,552 schoolchildren in a number of towns in the vicinity of Los Angeles, California. The measure of refractive error was by skiametry, with accommodation "relaxed physiologically" and reported as spherical equivalents. Means, medians, 7th, 25th, 75th, and 93rd percentiles, ranges in diopters for various percentages, and the percentages of cases having various refractive states are presented for the right eye for males and females at various ages. The percentage of children with myopia in excess of 1.00 D. is also presented by age and gender. For the purposes of Table B-3, the rates for males and females were averaged to obtain overall estimates of myopia prevalence in excess of 1.00 D. and the prevalence of any negative refractive error.

From 1966 through 1970, 6,768 youths ages 12 to 17 were examined as part of the Health Examination Survey, Cycle III (Roberts and Slaby, 1974). There was a 90 percent participation rate among subjects selected as a probability sample of noninstitutionalized youths. While there were no explicit criteria for myopia, 42 percent of those surveyed had a visual acuity less than 20/20 in one or both eyes, and 82 percent of these (i.e. 34 percent of those surveyed) required negative correction or showed "some evidence of myopia." This suggests an overall prevalence of myopia of 34 percent based on reduced visual acuity plus any negative correction on either a trial lens or the subject's own lens for either eye. Since the emphasis of this report is on visual acuity and the adequacy of the current correction, it is difficult to find basic age-specific prevalence information on myopia. However, these data were reanalyzed by Angle and Wissmann (1980a), who reported the age-specific prevalence of myopia (Table B-3) as a percentage of all eyes, based on a combination of: (1) the subject's own corrective lens having a negative spherical equivalent, (2) uncorrected visual acuity less than 20/20 and improved by a negative sphere trial lens, and (3) no vision problem not correctable with a lens. It would appear from the description that an eye with any negative spherical equivalent would be counted as myopic if the individual either wore corrective lenses or failed the visual screen for one or both eyes, but that many eyes with a small negative refractive error (up to −0.50 D.) might escape detection.

In 1971-1972, 9,263 people ages 4 to 74 were screened to detect refractive errors and motility defects (Roberts and Rowland, 1978). These individuals were from a 35-location subsample of the National Health and Nutrition Examination survey; there was a 71.6 percent response rate. There was no classification of "myopia" as such. In fact, different data were collected on different individuals depending on whether they brought corrective lenses with them, what their corrected or uncorrected visual acuity was, and whether they were in a subsample designated for retinoscopy. Figure B-2 is a flow chart illustrating the data collection procedure inferred from the report of this study. It provides a useful guide to the categorization of subjects by refractive error. Sperduto et al. (1983) published a reanalysis of 5,282 of these individuals ages 12 to 54, basing their classification of myopia on the refractive error from the subjects' lenses adjusted according to their visual acuity if their usual visual acuity was at least 20/40 and improved with pinhole testing, or usual visual acuity less than 20/40 and negative trial lens or retinoscopic refraction. Fifteen percent of individuals were not classified; the authors believe that that underestimated the prevalence of myopia by about 1 percent, but they do not refer to any dioptric criterion.

A comparison between the Washington, D.C., schoolchildren in 1924 at ages 12 to over 14 (Kempf et al., 1928) with the 1952 California schoolchildren at ages 11 to 14 (Hirsch, 1952) shows a higher prevalence of myopia (3.2 versus about 5 percent) greater than 1 D. in the latter. This difference is statistically significant at the 5 percent level based on a chi-square test under the assumption that Hirsch's age categories contain approximately

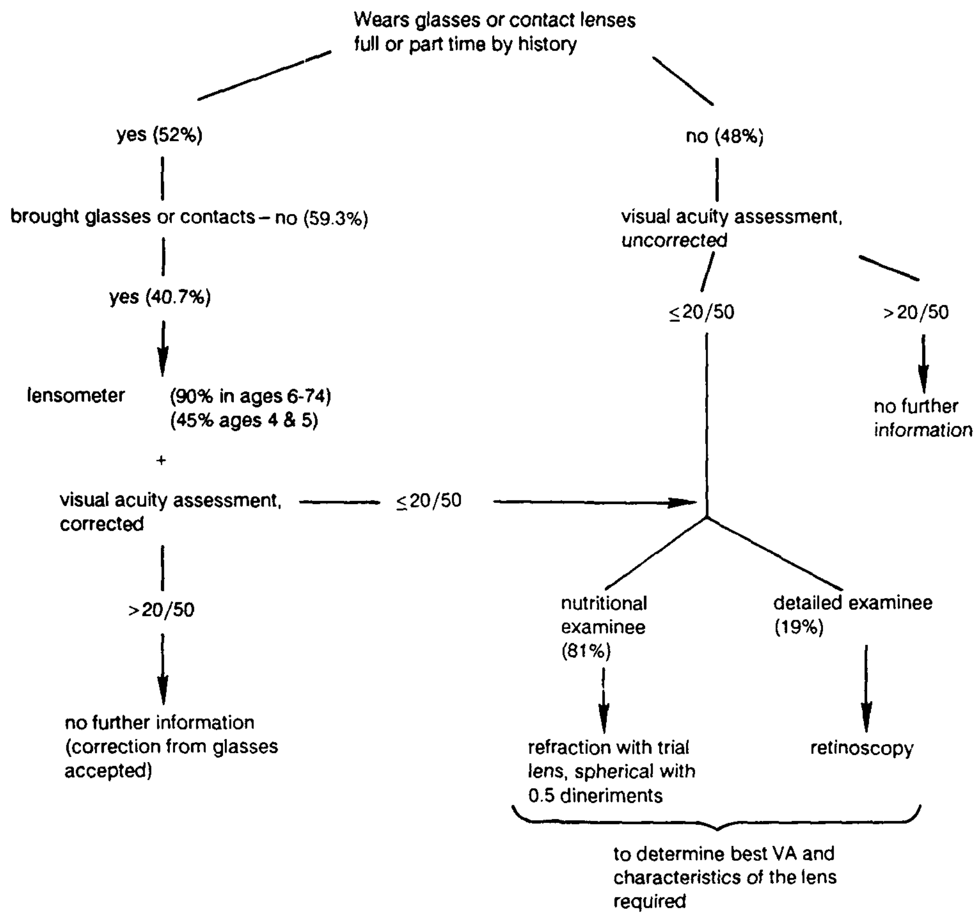

FIGURE B-2 NHANES data collection procedure.

Source: Adapted from Roberts and Rowland, 1978.

equal numbers (these are not given in his paper). A comparison based on a criterion of myopia of greater than or equal to 1.00 D. would lead to an underestimation of the difference between them. Other problems of comparability between these two studies include:

(1) Relaxation of accommodation: Kempf used cycloplegia, while Hirsch used convex lenses to relax accommodation.
(2) Summary of meridians: Hirsch reports spherical equivalents; Kempf et al. classified compound astigmatism according to the spherical correction (i.e., the axis with the smaller correction) and simple astigmatism according to the abnormal axis and excluded cases of mixed astigmatism from the analysis. These differences would yield a lower percentage of myopes in the Kempf et al. study compared to that of Hirsch.
(3) Reported categories of refractive error: Kempf et al. reported refractive error as 0.00, −0.25, −0.50, etc.; the actual cutoff point for each category is unclear. Hirsch reported categories as a range 1 D. wide (e.g., 0-1, 1-2, 2-3). Although one of the tables and the text indicate that the lower value was not actually included in each

category, prevalence estimates from Kempf et al. including −1.00 D. are included in Table B-3 to provide for a more "conservative" comparison.

(4) Population: the D.C. schoolchildren were all Caucasian, while the racial demographics of the California schoolchildren were not stated. In extracting and summarizing Hirsch's data, overall age-specific prevalences were taken to be the mean of the age- and gender-specific prevalences, whereas the estimates from Kempf et al.'s studies were based on the actual numbers of males and females in each age category. However, in no age category did either gender comprise less than 46 percent or more than 54 percent of the population. No other demographic characteristics of the population of either study are specified.

Comparison of Kempf et al.'s myopia greater than or equal to −0.25 D. with Hirsch's prevalence for all myopia (9 versus 24 percent) suggests the possibility of an even larger increase in low-order myopia at all ages, but the comparability of classification criteria is even less secure. Myopia greater than −1.00 D. in younger children appears to be about the same in both studies.

Due to the vagueness in the estimation of myopia prevalence from the national surveys, these data are difficult to interpret. An underestimation of myopia prevalence by 1 percent by Sperduto et al. (1983) does not explain the difference between his estimate of 24 percent of right eyes in 1971-1972 and Angle and Wissmann's estimate of 29.9 to 33.2 percent of eyes in 1966-1970. Furthermore, in their article on myopia and corrective lenses, Angle and Wissmann (1980a) state, "Cycle III of the Health Examination Survey showed that 23.6% of eyes free of a problem that cannot be corrected by lenses have a corrective lens with a negative spherical equivalent correction for myopia." Whether these discrepancies are due to criteria of classification, methods of classification, the use of a subset of the data, or some other factor is not clear. It is unlikely that there was a drop in myopia prevalence of 5 percent between the late 1960s and the early 1970s.

If the 24 percent estimate is to be believed, the data suggest that the U.S. myopia prevalence among 12- to 17-year-olds in 1970 was similar to that observed by Hirsch in California in 1952.

Japan

Sato (1957) references a number of studies that suggested a major increase in the prevalence of myopia in Japan between about 1911 and 1937, a reported drop in the prevalence of myopia during World War II, and then a subsequent increase.

Canada

Of particular interest are the data on changes in myopia prevalence with the introduction of schools to previously isolated communities. Although not fully documented by surveys, it has been generally accepted that, until recently, myopia was rare among Eskimos in Canada. Surveys in East Greenland (referenced by Alsbirk, 1979) and the Belcher Islands (Woodruff and Samek, 1976) indicate that myopia prevalence remains low among Eskimos in areas that are isolated and with no universal public education. The results of surveys among Canadian Eskimos and American Indians are described as showing an epidemic of myopia in the younger population.

Boniuk (1973) examined 951 northwestern Ontario Indians at Sioux Lookout in 1970-1971. The project was service-related and selection was by self-referral, although most school-age children were examined routinely. The highest proportion of the population

examined was 50 percent in Big Trout Lake and Fort Hope. Of those examined 53 percent were between the ages of 4 and 19. Moderate myopia, defined as -1.00 to −5.00 D. spheres based on retinoscopy under cycloplegia, was the most prevalent refractive error, peaking to over 50 percent in the second and third decade and then falling off markedly. The unusually high myopia prevalence reported in this study may be in part due to the use of positive cylinder. In this form the spherical component will, by convention, be more negative when expressed as a sphere combined with a positive cylinder (Woodruff and Samek, 1977).

Morgan and Munro (1973) examined 2,833 Eskimos and 844 Indians in the Yukon and Northwest Territories. These data were collected as part of a survey of selected settlements to determine eye care needs. Moderate myopia was defined as a refractive error of −1.00 to −5.00 D. based on retinoscopy under cycloplegia. The Eskimos and Indians were found to have similar patterns of myopia, peaking to a prevalence of about 30 percent at ages 15 to 20 and then dropping precipitously to under 10 percent at about age 30.

Woodruff and Samek (1977) examined 4,018 Cree Indians of northern Ontario (approximately 60 percent of the total population) in 1970 and 1971 as part of a program providing vision screening and care. Nearly all children in any school or community were included, whereas adults were more likely to have been self-selected. Refractive error was based on subjective and retinoscopic refraction expressed as the equivalent spherical refractive state (sphere plus 1/2 cylinder) for each eye; 47 eyes with a negative error greater than −7.00 D. were excluded. Internal inconsistencies in the reported total numbers and proportions make it difficult to summarize the results of the study; however, the general pattern is one of highest rates of myopia occurring among adolescents and young adults, with a considerable reduction after age 30. The reduction is almost certainly a result of reviewing cross-sectional data and does not reflect longitudinal changes but rather a change in the prevalence over different generations. The authors present figures comparing the percentage of myopic persons by age with Morgan's Sioux Lookout data. The peak prevalence for myopia from their data appears to be under 15 percent occurring between ages 10 and 14, a considerably lower and earlier peak than that shown by Morgan. The authors interpret this difference to reflect the fact that their sample is less selected than that of Morgan. The criteria for myopia for this figure are not stated, however, and a percentile table of spherical equivalent refractive states indicates a much higher prevalence of myopia: the prevalence of a negative refractive error greater than −1.00 D. was over 50 percent in the 17- to 20-year-old age group, falling below 25 percent after age 30 and below 15 percent after age 35.

This pattern, of a peak in myopia prevalence followed by a rapid decline, is what one might expect to see with a secular trend of increasing myopia. However, it could also be an artifact of sampling, and it is of concern to note that the pattern is less striking in studies with higher participation rates.

Richler and Bear (1980a) refracted 971 persons representing about 80 percent of the population of three isolated communities in western Newfoundland in 1974. The population was all Caucasian and there was no formal compulsory education in the area prior to 1949. Retinoscopy was performed with fogging to relax accommodation and then redefined subjectively to determine the maximum convex or minimum concave correction required for distant acuity of 20/20. Data for the right eye were presented. Myopia was defined as any negative refraction (i.e. myopia of any amount). The proportion of myopes peaked at ages 15 to 19 at 63.9 percent. By age 40 it had fallen below 20 percent and by 50 to about 10 percent. The authors compared the age curves for the prevalence of myopia in populations with the recent introduction of public education to those in which there had been public education for a long time, the latter showing a much more gradual decrease in myopia prevalence with age (Figure B-3).

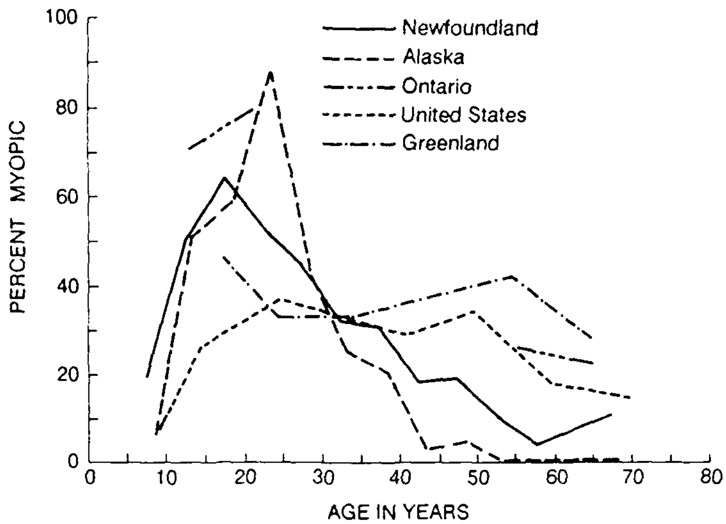

FIGURE B-3 Changes with age in proportion of subjects who are myopic in a comparison of five studies.

Source: Adapted from Richler and Bear, 1980.

Apart from secular trends and sampling bias, possible explanations for these findings are differential attrition among myopes and spontaneous regression of myopia. There is little evidence to support either of these possibilities.

ACTIVITIES

An association of myopia prevalence with certain activities including reading, is suggested by its association with some occupations, with education, and with reading measures.

Reading

Angle and Wissmann (1980a) used grade in school, reading test scores, and reported time spent reading magazines, books, and newspapers in a typical day as measures of near work and reading. All three were positively associated with myopia prevalence. Furthermore, the authors estimated refractive status for each individual and regressed myopia on the social variables of age, sex, race, income, and region. Upon adding the measures of near work to each regression equation, the regression coefficient for each social variable was reduced. The authors concluded that at least some of the social patterns of myopia variability can be explained by the measures of near work. This study has been criticized because refractive error was not measured directly but approximated from other measures, and because there was no control for other confounding, especially by age and ethnic background, when assessing the impact of the near-work variables (Taylor, 1982).

Near Work

When Richler and Bear (1980a) measured the refractive status of 971 people in three communities of Newfoundland, they also obtained data on near work, measured as hours per day spent at tasks requiring focusing of the eyes at a distance of 20 inches or less, as reported by the subject, and education measured in years at last completed grade. Results

were presented separately for five age strata. Refraction and near work were significantly negatively correlated (indicating a positive correlation between near work and myopia) for all age strata except age 60 and over. These correlations remained significant after controlling for age, sex, and education.

Occupation

The prevalence of myopia is not uniform over occupational groups. Kantor, for example (summarized by Sorsby, 1932), reported a higher prevalence of myopia in type compositors than noncompositors, both among Jews and White Russians. Goldschmidt (1968) alludes to many studies in Europe illustrating associations with categories of occupation, which are based on education and quant.ty of close work. His data on military conscripts and those of Tscherning (1882), when classified according to occupation, revealed a prevalence of myopia that varied from a low of under 3 percent in category six—intended to include men who use their eyes least for close work (e.g., farm laborers, seamen, unskilled and semiskilled workers)—to a high of over 30 percent in category one, which was comprised mainly of students. Goldschmidt (1968) also describes reports of specific occupations in which workers have a high probability of having myopia. For example, women employed in finding and repairing weaving faults in a clothing mill, textile workers, and compositors have all been found to have a high frequency of myopia, which tends to increase with the numbers of years spent in the trade. This increase in myopia prevalence could be due to the effect of the work, but it could also be explained by increasing loss of nonmyopes from the trade with increased age.

Kinney et al. (1979) summarized three studies concerning the association of the occupation of submariners with the development of myopia. This possible association is interesting but unconfirmed. Provines et al. (1983) found that navigators were more likely to become myopic than pilots. Since these studies concern the development of myopia in visually selected groups, they do not address myopia prevalence.

ACADEMIC ABILITY

In addition to Angle a d Wissmann (1980a), several other authors, including Krause et al. (1982) in Finland and Peckham et al. (1977) in England, Scotland, and Wales, have reported associations between myopia and academic ability. Academic ability, however measured, is probably related to both intelligence and time spent reading. Dalton (1943) studied nearly 6,000 California schoolchildren and found no difference in academic achievements between children with sufficiently defective vision to notify their parents and a random sample of children with normal vision. Since reduced visual acuity alone is an inadequate indicator of myopia, the results of the study are essentially uninformative.

Rosner and Belkin (1987) recently conducted a nationwide survey in Israel noting the refractive error and intelligence scores among 157,748 males age 17-19 years. This represents a largely unselected study population since all Jewish males age 17-19 undergo medical examination to check fitness for military service. Refractive error was measured only for those who had less than 20/25 vision in either eye (assuming this criterion screened for myopia). They found that both "years of schooling" and "intelligence" weighed approximately equally in their significant positive correlation with myopia.

OTHER CHARACTERISTICS

Socioeconomic Status

Angle and Wissmann (1980a) and Sperduto et al. (1983) both report an association between myopia prevalence and income in the United States. Krause et al. (1982) report an association with myopia with social classes in Finland. Peckham et al. (1977) report that the prevalence of myopia in 11-years-olds was higher for children in "non-manual families" than in "manual families." In addition, they report a higher prevalence in small families than in large families, higher in the first child compared with subsequent children, and higher in children whose parents showed an interest in school progress compared with children whose parents were not interested.

Urban/Rural Residence

Jain et al. (1983) and Paritsis et al. (1983) report a higher prevalence of myopia among urban residents. Angle and Wissmann (1980a) report no relation between the prevalence of myopia and the degree of urbanization of the place of residence.

Height and Weight

Several investigators (Johansen, 1950; Pendse and Bhave, 1951; Krause et al., 1982) report an association of greater myopia prevalence or negative refractive error with height and weight in children. It has been suggested that, as with gender differences, this is due to an association of both variables with developmental maturity. Goldschmidt (1968) studied the relationship of myopia and height among 3,511 conscripts. He found that the myopes were significantly taller than nonmyopes in the group as a whole, but that there was no significant difference within occupational category.

Low Birthweight

Fledelius (1980) examined a subset of members of two cohorts, one of premature infants with low birthweight and one of full-term infants, who had reached age 18. An effort was made to identify all individuals who had become myopic by using school records. The 18-year incidence of myopia was 17.6 percent for the low-birthweight group and 13.1 percent for the full-term group. The author regards these as minimum incidences, because some individuals with myopia may not have been recorded in school medical records. The higher incidence in the low-birthweight group appeared to be due to 16 cases designated as having "myopia of prematurity." When these 16 cases were excluded, the proportion of myopia in the two groups was quite similar.

Genetic Factors

In an analysis of family variations in refractive error and optical components of the eye, Alsbirk (1979) found an apparent lower inheritability for refractive error than for axial length, corneal curvature, or chamber depth. Siblings showed a greater similarity with respect to refractive error than did parents and children. The authors proposed that the influence of a common familial environment best explained these findings, although genetic factors are theoretically also possible.

Goldschmidt (1968) provides an extensive review of the literature on genetics in myopia as well as his own investigation. He concludes that genetic factors are important in the etiology of myopia, but that there are several types of myopia with different genetic patterns.

Basu and Jindal (1983) studied myopia among the Dawoodi Bohras of India, a highly inbred group. They examined members of 92 families, in each of which at least one member had myopia. Myopia was found to be associated with consanguinity and low birth order. In addition to the absence of specification of selection criteria or definition of myopia, ages were not specified, and it is therefore uncertain whether the compared groups had similar age distribution.

Geographic Correlates

Daubs (1984) used data collected from 1967 to 1970 in 16 U.S. states of the model reporting area to look for correlates of the incidence of malignant myopia. This study is analogous to early dental caries research and, like dental caries, malignant myopia was found to be inversely related to annual hours of sunshine, distance to the seacoast, and fluoride and calcium levels. The author also mentions his clinical impression that myopic patients have more dental defects.

Appendix C
Review of the Progression Literature

There is considerable proliferation and overlap of terminology in studies of myopia. The phrase ***myopia progression*** as it is used here refers to an increase with time in the negative sphere dioptric power necessary for correction to best visual acuity. This should not be confused with ***progressive myopia***, which is degenerative or pathological in nature. Myopia progression can occur either in simple myopia, in which the eye is anatomically normal, healthy, and capable of normal corrected visual acuity. It can also occur in pathological myopia, in which the eye ophthalmoscopically or otherwise shows visible pathological signs, or has substandard corrected visual acuity, or both (Curtin, 1966, 1979). The studies discussed below deal almost exclusively with myopia progression in simple myopia.

REFRACTIVE CHANGES IN THE FIRST SIX YEARS OF LIFE

Refractive changes in the first six years of life are not usually included under the term *myopia progression*, nor have they been extensively studied, but they are briefly summarized here to provide a background for discussions of myopia progression in the school-age years. Longitudinal studies remain to be done, but refractive changes over this time span can be implied from refractive error distributions at different ages (Hirsch, 1963). Such a comparison is made in Figure C-1. Cook and Glasscock (1951) measured refractive errors of 500 30-hour-old infants (185 white infants, 315 black infants) by retinoscopy under atropine cycloplegia at the University of Arkansas School of Medicine Hospital. Most frequent was hyperopia of 1.00 to 2.00 diopters (D.), with a range of −12 to +12 D. of the 1,000 eyes thus measured: 74.9 percent were hyperopic or emmetropic and 25.15 percent were myopic. Kempf et al. (1928) took retinoscopic measurements of 333 white 6- to 8-year-olds in Washington, D.C., under homatropine cycloplegia. The distribution of refractive errors was highly leptokurtic, with a peak at 0 to 1.00 D. of hyperopia and a range of −3.00 D. to +3.00 D. About 97 percent of these children were hyperopic or emmetropic. While the populations from which these samples were taken were diverse, comparison of the two distributions would suggest that the variance of refractive errors reduces over the first six years of life, some children becoming less myopic and some becoming less hyperopic.

Mohindra and Held (1981) reported a cross-sectional study of 400 full-term healthy infants and children of ages from birth to 5 years, recruited from Boston and Cambridge, Massachusetts, by mailings. Of these 400 infants and children, 312 were ages 0 to 2 and 88 were between ages 2 and 5. Spherical equivalent refractive errors were determined by

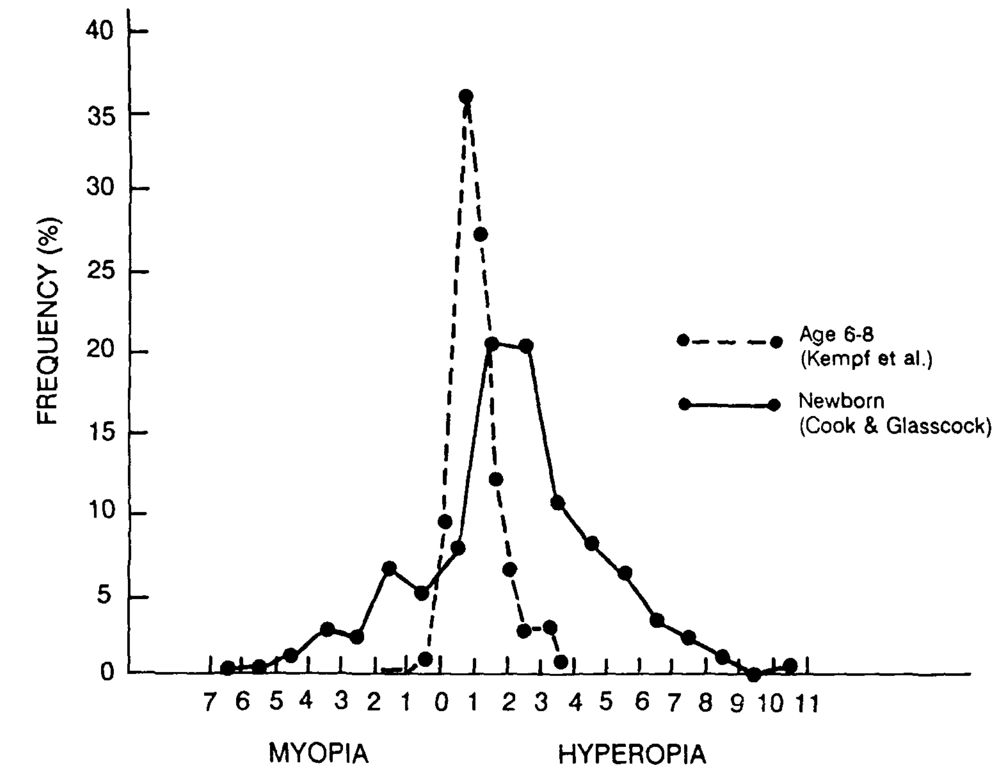

FIGURE C-1 Refractive error distributions for newborns based on the data of Cook and Glasscock (1951) and for 6- to 8-year-olds from the data of Kempf et al. (1928).

Source: Adated from Hirsch, 1963.

a noncycloplegic retinoscope technique that Mohindra and Held called "near retinoscopy" (described by Mohindra, 1977; Borghi and Rouse, 1985). The refractive error distribution for the neonates (0-4 weeks) was very similar to the data from Cook and Glasscock (1951), with the exception that the distribution from Mohindra and Held (1981) was shifted toward myopia—a difference that could be explained in part by differences between cycloplegic and noncycloplegic results. Mohindra and Held found that in sequential groups from ages 0-4 weeks to ages 129-256 weeks, the prevalence of myopia and astigmatism declined, the prevalence of emmetropia (0 ± 0.99 D.) increased, the prevalence of hyperopia remained about the same, the mean refractive error shifted toward hyperopia, and the range and standard deviation of refractive errors decreased.

Studies by Mohindra et al. (1978) using near retinoscopy and by Howland et al. (1978) using photorefraction suggest that relatively high amounts of astigmatism are quite prevalent among infants. Three additional studies (Dobson et al., 1984; Gwiazda et al., 1984; Howland and Sayles, 1984), each using a different refractive technique (retinoscopy under cycloplegia, near retinoscopy, and photorefraction, respectively) suggest that this is predominantly against-the-rule astigmatism and that it decreases in amount over the first few months of life, so that by about age 4, with-the-rule astigmatism is more prevalent.

Premature infants quite often have severe myopia, which is more common as birthweight decreases over the first few months of life; many infants become emmetropic by age one year (Fletcher and Brandon, 1955; Scharf et al., 1975; Yamamoto et al., 1979). Myopia of high

degree also tends to develop in eyes with retrolental fibroplasia, which is often associated with premature birth (Yamamoto et al., 1979). Rabin et al. (1981) proposed that the opacification of the ocular media in retrolental fibroplasia leads to the severe myopia, and that this is comparable to the myopia that has been produced experimentally by depriving animals of clear retinal imagery (Wiesel and Raviola, 1977, 1979; Goss and Criswell, 1981; Criswell and Goss, 1983). Reviews on the relationship of refractive error to premature birth are available in the literature (Banks, 1980; Goss, 1985).

JUVENILE MYOPIA

Typical Changes During the School-age Years

During the middle of this century, thought on refractive changes was dominated by concepts from cross-sectional and partially longitudinal studies of private practice records (Brown and Kronfeld, 1929; Jackson, 1932; Brown, 1938, 1942; Slataper, 1950). Cycloplegic refraction was negative in sign from age 6 or 7 until the early 30s, the changes being lower in magnitude after the middle teens. Brown and Kronfeld interpreted the ages 7 to 17 as the "period of progression." Slataper suggested that there were phases of refractive change corresponding to different periods of the life-span: (a) the axial myopic change of the young, involving an average change of −3.33 D. from between ages 8 and 30; (b) the hypermetropic change of middle age, involving an average change of +1.36 D. between ages 31 and 64; and (c) senile myopic change, involving an average change of −2.37 D. between ages 65 and 87. Slataper (1950) also recognized that refractive changes were greater for myopic eyes than for hyperopic eyes. He reported an average annual change between ages 8 and 22 of −0.29 D. for 1,704 myopic eyes and −0.14 D. for 2,003 hyperopic eyes.

Hirsch (1961, 1964a, 1964b) reported on a twice yearly manifest retinoscopy of schoolchildren in Ojai, California. He started with 1,200 5- or 6-year-olds and was able to follow about 500 of them until ages 13 or 14. Hirsch (1964b) found that the refractive error at ages 5 to 6 did have some predictive value for refractive error at ages 13 to 14. He proposed that: (a) if a child has any degree of myopia at ages 5 to 6, the myopia will probably increase; (b) if a 5- to 6-year-old child has a refractive error of +0.50 to +1.25 D., he will most likely be emmetropic at ages 13 to 14 but may also show myopia or hyperopia; and (c) with refractions between 0 and +0.50 D. at ages 5 to 6, a child will probably be myopic by ages 13 to 14. He also noted that children who had 0.25 D. or more against-the-rule astigmatism when entering school were more likely to develop myopia than children with spherical refractions, a relationship that was significant by chi-square analysis. Hirsch's studies and Langer's, cited below, indicate that the majority of children in a unselected sample have relatively small changes in refraction, and the myopes are set apart by their rapid changes by comparison.

Langer (1966) reported on a similar vision survey of schoolchildren in Leaside, Ontario, a suburb of Toronto with a population of generally high socioeconomic status. Children were seen in grades K, 1, 3, 5, 7, 9, 11, and 13. Refractive measurements were made by manifest retinoscopy; spherical equivalents were used for analysis. The number of refractions per child ranged from 3 to 9 (mean 6.9). For children ages 5-6 through 15-16, the percentage who were myopic (any amount of negative refractive error) increased, and the percentage of hyperopes (+1.00 D. refractive error or more) decreased. Both Hirsch (1961) and Langer found that the majority of individual plots of refractive error with age were linear. Langer noted that most of the nonlinear individual plots had slopes that were closer to zero. In 81 percent of the subjects, Langer was able to predict the final refraction within 0.50 D. by

linear extrapolation from the first three data points, even though 82 percent of the cases had a time interval between the first and third points of less than 3.5 years.

A study by Hofstetter (1954), although derived from a selected sample, emphasizes the difference in refractive changes between myopes and nonmyopes. The data used were manifest subjective refractions from the office of an optometrist in Bloomington, Indiana. Hofstetter calculated the dioptric change per month, using the mean of the spherical equivalents of the two eyes. For the 10- to 20-year-old age group, the majority of myopes showed negative rates or further increase in myopia. Those subjects who were emmetropic or hyperopic showed relatively less change (mean and mode rate both near zero), with some showing positive shifts and some negative shifts.

To summarize the changes typical of childhood, most children show a low negative rate of change in refractive error, but in most cases this does not result in myopia. Hyperopes have been reported to have relatively stable refraction. Some of the apparent shifts toward more hyperopia may represent latent hyperopia becoming manifest. Myopes are readily distinguishable by their relatively high rates of refractive change (compared with nonmyopes), which typically stops or slows appreciably during the middle or late teens. Refractive error distributions remain leptokurtic from age 6 to the teenage years, with the skew shifting from hyperopia to myopia.

The studies on age of onset of myopia progression, rates of childhood progression, and age of cessation discussed below are drawn almost exclusively from private practice records of myopes. While this means, of course, selected samples, it is perhaps less of a detriment in studying myopia progression than it would be in studying population characteristics. Even in the absence of regular changes in spectacle correction necessitated by the increases in myopia, myopes may be likely to return to the practitioner due to breaking or outgrowing their spectacle frames.

Age of Onset

The incidence of myopia increases throughout the childhood years, beginning at about age 5 or 6. This is illustrated by the vision surveys done by Hirsch (1952) and Young et al. (1954b). Hirsch reported on the spherical equivalent refractive errors of the right eye, determined by manifest retinoscopy, of 9,552 randomly selected elementary schoolchildren from the Los Angeles area. Included were children between the ages of 5 and 14 at the nearest birthday. Young et al. (1954a and b) made a survey of several visual characteristics of 652 schoolchildren in Pullman, Washington, a college town in a wheat farming area of southeastern Washington. Young et al. stated that the largest occupational groups in Pullman were college instructors and farmers. Young et al., like Hirsch, used spherical equivalent refractions for the right eye determined by manifest retinoscopy. The myopia prevalence data from these studies, as well as those from Langer (1966), are summarized in Table C-1. Each of these studies shows an increase in prevalence with age. It may be noted that the largest increase in prevalences for girls occurs between the 7-8 and 9-10 age levels for both the Hirsch (1952) data for all myopes and the Young et al. (1954b) data. For boys the largest difference occurs between ages 9-10 and 11-12; this would imply that the most common ages of myopia onset are about age 9-10 for girls and age 11-12 for boys.

Rosenberg and Goldschmidt (1981) selected patient records from the 1974 to 1979 files of an ophthalmologist in Denmark. Included were patients age 20 years or less, examined at least twice, with a minimum observation period of 12 months. A total of 280 cases of myopia (122 males and 158 females) were thus collected. Refraction was by noncycloplegic subjective refraction or by subjective refraction under 1 percent cyclopentolate in cases of

TABLE C-1 Myopia Prevalence Among U.S. Schoolchildren in Various Populations, 1952-1966

	Hirsch (1952)				Young et al. (1954)		Langer (1966)			
	Myopia of any amount		Myopia > 1 D.		Myopia > 1 D.		Myopia of any amount		Myopia > 1 D.	
Age	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys
5-6	6.15	7.43	0.45	0.67	4.17	0.00	2.04	0.00	0.00	0.00
7-8	9.71	11.02	0.98	0.90	2.60	5.62	3.97	3.08	0.00	1.54
9-10	17.18	15.68	2.01	1.82	19.44	9.68	12.20	11.68	6.71	5.11
11-12	21.60	20.74	5.77	3.08	20.00	27.27	29.18	20.48	10.26	5.71
13-14	25.36	22.53	5.78	5.08	25.71	28.57	34.42	34.30	19.48	15.01

suspected unrelaxed accommodation. The age of myopia onset was defined as the age at the first examination revealing myopia, or as the age at which corrective lenses were prescribed for those patients already wearing them. The most common onset age for the boys was at 11-12, whereas the distribution for girls peaked at ages 9-10 and 11-12.

Septon (1984) distributed to 500 students in six consecutive second- year optometry classes at Pacific University in Oregon a survey form with entries for the spherical equivalent refractive error of the student's more ametropic eye as determined during the previous year, and for the age at which myopic students first wore corrective lenses. Of the 500 students, 398 were males, and 89 percent were Caucasian. Of the 447 students who responded to the survey, 332 were myopes. Septon concluded that the ages at which myopes first present for care tend to cluster in three groups: major ones at ages 8-9 and 12-13 and a minor one at age 19.

Bucklers (1953) in Germany and Lecaillon-Thibon (1981) in France proposed on the basis of subjective examination of patient records that the earlier in childhood that myopia is discovered (and presumably the earlier it begins), the greater is the subsequent progression. This has been confirmed by several studies (Fletcher, 1964; Francois and Goes, 1975; Rosenberg and Goldschmidt, 1981; Septon, 1984; Mantyjarvi, 1985a; Goss and Cox, 1985).

Rosenberg and Goldschmidt (1981) calculated the amount of increase of myopia in terms of the mean of the spherical equivalents of the two eyes and related it to the age of myopia onset. Higher amounts of increase were more common among those with earlier onset ages. They also reported that, for 30 girls with onset at age 9-10, the average annual increase in myopia in the right eye was 0.47 D. (SD = 0.28), whereas for 36 girls with onset at age 11-12, the average annual increase was 0.37 D. (SD = 0.42). Thus, an earlier onset may be associated with a higher rate of progression.

Mantyjarvi in Finland presented data on 214 myopic children (136 girls and 78 boys), ages 7 to 15, followed for 1 to 9 years and examined in the Kuopio, Finland, Community Health Center. Refractive values used were the right eye spherical equivalents as determined by retinoscopy using 1 percent cyclopentolate. The definition of age of myopia onset as used in this study was not given. Results on the amount of myopia at age 15-16 as it related to the onset age are summarized in Table C-2. For both boys and girls, the amount of myopia was greater for earlier onset ages. Mantyjarvi was cautious to point out, however, that

TABLE C-2 Mean Amount of Myopia at Age 15-16 According to the Age of Myopia Onset

Age of myopia onset		N	Final refraction Mean	SD
7-8	Girls	3	-6.17	1.20
	Boys	6	-4.42	2.04
9	Girls	8	-4.91	2.52
	Boys	9	-4.06	0.95
10	Girls	8	-4.00	1.14
	Boys	6	-4.33	0.88
11	Girls	32	-3.27	1.26
	Boys	15	-3.00	1.40
12	Girls	34	-2.82	1.06
	Boys	15	-2.63	1.14
13	Girls	20	-2.59	0.95
	Boys	6	-2.42	0.77
14	Girls	16	-2.09	1.18
	Boys	12	-2.13	0.94
15	Girls	15	-1.23	0.67
	Boys	9	-1.00	0.52
7-10		40	-4.46	1.63
11-13		122	-2.87	1.15
14-15		52	-1.66	1.00

SOURCE: Mantyjarvi (1985a).

there was considerable individual variation, as can be noted from the standard deviations in Table C-2. Of children with onset before age 10, 12.5 percent remained below 3.00 D. of myopia, 70 percent developed myopia of 3.00 to 5.75 D., and 17.5 percent had myopia of 6.00 D. or more. Of those children with onset at ages 11-15, 66.7 percent had less than 3.00 D. of myopia at age 15-16, 32.2 percent ended up with 3.00 to 5.75 D. of myopia, and 1.1 percent reached 6.00 D. or more myopia.

Goss and Cox (1985) presented data from private optometry practice records obtained from five locations in the central United States. The refractive data used were the refractive errors in the principal meridian nearest horizontal in the right eye as derived from the manifest subjective refraction recordings. A linear regression equation of diopters of refractive error versus age in years was calculated for subjects with four or more refractions between the ages of 6 and 15. An index of age of myopia onset was determined by extrapolation to zero refractive error. An index of the final amount of myopia after childhood myopia progression was derived from the mean of the amount of myopia found at examinations after age 17. The coefficients of correlation of onset age and final amount of myopia were 0.42 for males ($n = 49$), and 0.61 for females ($n = 31$). Both of these correlations were statistically significant at the 0.01 level.

These studies indicate that myopia continues to increase in prevalence throughout the school-age years, that girls have earlier onset ages, and that the earlier myopia appears, the more likely it will progress to a high degree.

Rates of Progression

For Hirsch's (1964a) nonvisually selected sample, the average rate of refractive error change was –0.07 D./yr. (SD = 0.09). He stated that rate of change for myopes was higher than for the rest of the sample. Most of the reports in which rates of childhood myopia progression are given are studies of various treatment modalities tested for their ability to alter the course of myopia development (Goss, 1982). Control group data can be used to get an idea of common rates. In the United States, mean rates of childhood myopia progression were in the neighborhood of –0.30 to –0.60 D./yr. (Nolan, 1964; Roberts and Banford, 1967; Baldwin et al., 1969; Oakley and Young, 1975; Goss, 1984), whereas in Japan mean rates were in the area of –0.50 to –0.80 D./yr. (Tokoro and Kabe, 1964, 1965; Matsuo, 1965; Otsuka, 1967).

Mantyjarvi (1985b) provided a comparison of rates of refractive change for 46 hyperopes (32 girls and 14 boys) and 133 myopes (75 girls and 58 boys), who were followed for observation times varying between 5 and 8 years, up to age 15. Refractions were spherical equivalents in the right eye under 1 percent cyclopentolate cycloplegia. The children were seen annually or biennially in most cases. They were examined at the Kuopio, Finland, Community Health Center following a screening by school doctors and nurses. The mean (± SD) annual rate of change for the hyperopes was –0.12 D./yr. (± 0.14), with a range of +0.11 to –0.45 D./yr. For the myopes, the mean (± SD) was –0.55 D./yr. (± 0.27), with a range of 0.00 to –1.63 D./yr. Mantyjarvi (1985b) also reported on 30 schoolchildren who were initially hyperopic but became myopic during the observation time. The mean (± SD) rate while they were hyperopic was –.021 D./yr. (± 0.21), with a range of +0.25 to –0.75 D./yr. The mean (± SD) rate while they were myopic was –0.60 D./yr. (± 0.45), with a range of –0.08 to –1.63 D./yr. It would appear that the rate of refractive change accelerates about the time a child becomes myopic.

Goss and Cox (1985) reported on longitudinal records of 559 myopes from five optometry practices collected on the basis of the following criteria: (1) at least four examinations

TABLE C-3 Frequency Distribution of Rates of Childhood Myopia Progression for Patients from Five Optometry Practices in the Central United States

Range of Myopia (D.)	Males (N)	Females (N)
+0.20 to 0.00	0	4
-0.01 to 0.20	37	20
-0.21 to -0.40	51	48
-0.41 to -0.60	41	44
-0.61 to -0.80	15	23
-0.81 to -1.00	12	7
-1.01 to -1.20	2	1
-1.21 to -1.40	0	0
-1.41 to -1.60	0	1

SOURCE: Goss and Cox (1985).

between ages 6 and 24, (2) myopia of at least 0.50 D. sometime during the course of the clinical record, (3) astigmatism never manifested in excess of 2.50 D., (4) no strabismus or amblyopia, (5) no contact lens wear prior to the last refractive data recorded for use in this study, (6) no ocular pathology, and (7) no systemic pathology that might affect ocular findings, such as juvenile diabetes or other conditions. The refractive data used were refractive errors in the principal meridian nearest horizontal in the right eye as derived from the manifest subjective refraction recordings. Rates of childhood myopia progression in diopters per year were calculated by linear regression, using points at or before age 15 in those cases in which four or more refractions were recorded during that age span. Rates were thus determined for 158 males and 145 females. The mean rates of progression were −0.40 D./yr. (SD = 0.24; range = −0.01 to −1.09 D./yr.) for males, and −0.43 D./yr. (SD = 0.25; range = +0.12 to −1.52 D./yr.) for females. The difference in these means was not statistically significant at the 0.05 level. A frequency distribution of the rates is shown in Table C-3. Most rates fell within the −0.21 to −0.40 D./yr. and −0.41 to −0.60 D./yr. ranges. While there was considerable individual variation, positive rates (indicating a decrease in myopia) and rates more negative than −1.00 D./yr. were uncommon.

Cessation Age

Ophthalmic clinicians have long recognized that childhood myopia progression stops or slows down in the middle to late teens. Bucklers (1953), for instance, noted this from

examination of patient records from his practice. The average annual refractive changes in the data of Brown (1938, 1942) and Slataper (1950), which also included emmetropes and hyperopes, were less negative after about age 16.

Goss and Winkler (1983) investigated this on a quantitative basis. They selected 299 longitudinal records of myopic patients from three optometry practices. These were the first 299 records collected in the larger sample of Goss and Cox (1985). The refractive data were manifest subjective refractions. Examples of plots of myopia progression in individuals from this sample are shown in Figure C-2. The model used by Goss and Winkler was one of two straight lines, one through the points during the time when childhood myopia progression was occurring and another through points at later ages, with the cessation age being the point at which the two lines met. On the basis of this model, they determined cessation age by four different graphical and statistical methods. The mean cessation age for females was earlier than that for males, the difference generally being about one year. While the most common cessation ages were in the middle teens (about age 15 for females and age 16 for males), considerable individual variation was noted, with standard deviations of around two years.

Goss and Cox did not find a statistically significant correlation between onset age, as derived by the method described above, and cessation age, as derived by Goss and Winkler's method 2. The coefficients of correlation were 0.07 for males (n = 49), and 0.31 for females (n = 31). This would imply that the duration of childhood myopia progression is not constant from one individual to another.

The cessation age could be viewed as a point of transition from the generally rapid childhood myopia progression to a period of relatively smaller or negligible increases in myopia. The increases in myopia that do occur after the cessation age, especially after ages 18-20, are referred to in this appendix as young adult myopia progression.

YOUNG ADULT MYOPIA

Variables Affecting Progression

Numerous factors undoubtedly affect the progression of myopia. These may include growth, health, nutrition, personality, race, ethnic heritage, hereditary factors, near work, and education (Baldwin, 1964, 1981; Goldschmidt, 1968; Borish, 1970; Curtin, 1970; Sorsby, 1979; Angle and Wissmann, 1980a). Studies are needed to effectively and systematically investigate these factors. One variable that is known to affect progression is gender (Weale, 1983). As shown above, females have earlier onset age and earlier cessation age than males. Astigmatism may be a factor in myopia progression (Baldwin, 1957; Hirsch, 1964b; Fulton et al., 1982). It has also been noted that, among strabismics and amblyopes, refractive changes are greater in the fixating eye than in the deviating eye (Lepard, 1975; Leffertstra, 1977; Bielik et al., 1978; Nastri et al., 1984).

Numerous attempts made to control the progression of myopia have been reviewed by Baldwin (1967), Borish (1970), Grosvenor (1980, 1982), Goss (1982), and Grosvenor et al. (1987). No method has been shown to be consistently and universally effective. Apparent success in reducing rates of myopia progression in some reports could possibly be attributed to investigator bias, inadequate experimental design, poor matching of experimental and control groups, and numerous uncontrolled variables. The most common treatment modalities have been rigid contact lenses, cycloplegic drugs, and bifocal lenses. The success of rigid contact lenses in controlling myopia progression can be attributed to flattening of the cornea, which causes reduction in the refractive power of the eye. In the only study in which

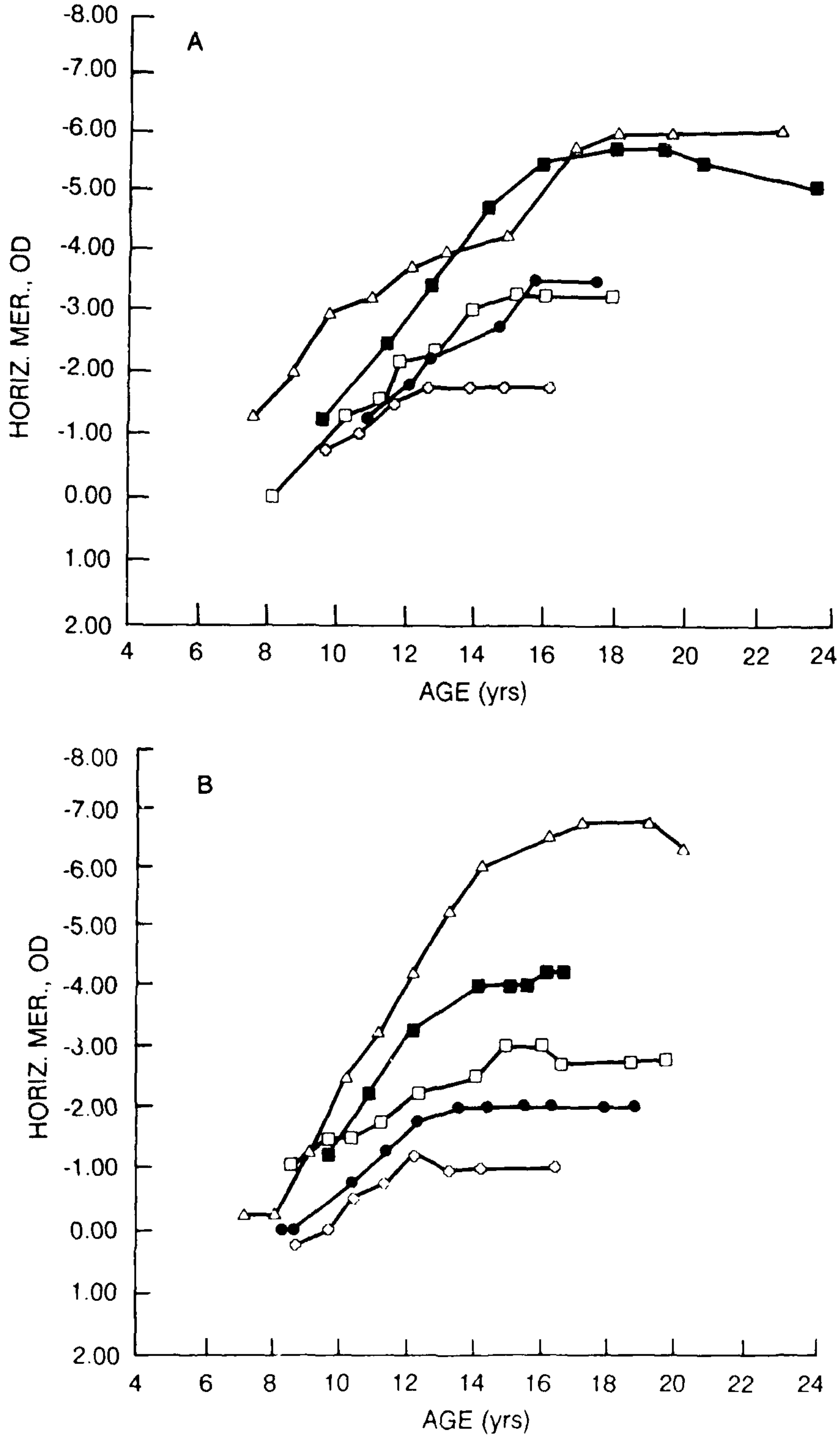

FIGURE C-2 Examples of myopia progression in five males (A) and five females (B) from north central United States private practice records: plotted on the abscissa is age in years, and on the ordinate is refractive error in the principal meridian nearest horizontal in the right eye. Each set of common symbols represents one individual.

Source: Adapted from Goss and Winkler, 1983.

corneal curvature changes were controlled (Baldwin et al., 1969), refractive error changes and axial length increases in rigid contact lens wearers and spectacle lens wearers were similar. Studies with cycloplegic drugs have not considered the effect of long-term reduction in ciliary muscle tonus on the results. That is, apparent reductions in rate may represent continued reduction in baseline ciliary tonus (Sato, 1957) rather than prevention of axial elongation. The disadvantages of long-term application of cycloplegics include compliance and their substantial visual and potentially systemic side effects. The results of studies on bifocals have varied widely. Potential explanations for this, in addition to those mentioned above, include the manner in which the bifocals were employed and the types of cases in which they were used. It is possible, for instance, that bifocals may be effective in the types of cases in which they reduce asthenopia, i.e., high lag of accommodation (accommodative response lags behind the accommodative stimulus) (Roberts and Banford, 1967; Goss, 1986a) and near-point esophoria.

Typical Refractive Changes in Young Adults

The majority of pertinent studies in this area deal with selected samples. Brown (1942), in his study compiled from cycloplegic refractions in a private practice, found mean annual refractive error changes that were negative in sign from ages 6 to 34. In Slataper's (1950) series, they were negative from ages 7 to 31. The magnitude of the average changes were much less after about age 18 or 20 than they were in childhood (see Table C-4). In Hofstetter's (1954) sample of private practice patients in Bloomington, Indiana, most persons in the 21- to 34-year-old age range showed little or no change in refractive error. Most of the myopes who did change became more myopic, and most of the hyperopes who changed became more hyperopic. While stable refraction was the rule for emmetropes, changes in both directions did occur. Since the data in Hofstetter's study were based on manifest refractions, some of the shifts toward hyperopia were probably due to manifestation of previously latent hyperopia.

Grosvenor (1977a, 1977b, 1977c) conducted a mail survey of male optometrists' own spectacle corrections from ages 20 to 40. He asked only for the spectacle correction, not the refractive error. Analysis was based on the most positive meridian of the right eye. At age 20, 59 (53.2 percent) of the subjects were in the emmetropic group (plano to +0.87 spectacle correction); at age 40, 44 (39.6 percent) of the subjects were in this group. The hyperopic group (+1.00 and over) had a net gain of 10 subjects, and the myopic group (any amount of negative power spectacle correction) had a net gain of 5 subjects during the 20-year period. For the 59 subjects originally in the emmetropic group, 24 had no change in spectacle correction over the 20 years, 22 had a change in the positive direction (toward hyperopia), and 13 had a negative change, the maximum being −1.50 D. For the 41 subjects originally in the myopic group, 12 had no change in spectacle correction, 4 had a positive change, and 25 had a negative change, the maximum being −2.00 D. For the 11 subjects originally in the hyperopic group, 4 had no change, 6 had a positive change, and 1 had a negative change. The mean spectacle correction was −0.08 D. (SD = 1.47) at age 20 and −0.18 D. (SD = 1.92) at age 40.

Morgan (1958, 1960) presented a longitudinal study in California of individuals seen 20 years apart, first at about age 13 in 1934, and later at about age 33 in 1954. In all, 51 females and 44 males consented to return 20 years after the study done on about 150 students entering seventh grade in two junior high schools. Vertical and horizontal meridians from the subjective refraction were both used for analysis. The mean change in refractive error was negative in sign. The number of emmetropes decreased over the 20-year

TABLE C-4 Average Annual Refractive Error Changes (D.) for Two Series of Private Practice Patients

Year of Life	Brown (1942)	Slataper (1950)
10th	-0.21	-0.26
11th	-0.25	-0.27
12th	-0.26	-0.30
13th	-0.27	-0.31
14th	-0.27	-0.29
15th	-0.21	-0.26
16th	-0.21	-0.17
17th	-0.12	-0.19
18th	-0.12	-0.15
19th	-0.10	-0.14
20th	-0.07	-0.14
21st	-0.06	-0.12
22nd	-0.08	-0.09
23rd	-0.07	-0.08
24th	-0.05	-0.06
25th	-0.05	-0.05
26th	-0.04	-0.04
27th	-0.02	-0.04
28th	-0.04	-0.03
29th	-0.02	-0.03
30th	-0.02	-0.02
31st	-0.05	-0.01
32nd	-0.02	-0.00
33rd	-0.09	+0.01
34th	-0.02	+0.01
35th	+0.04	+0.02
36th	-0.02	+0.02
37th	+0.01	+0.03
38th	+0.09	+0.02
39th	+0.04	+0.01
40th	+0.01	+0.01

span. Some hyperopes became more hyperopic, which may again be explained by latent hyperopia becoming more manifest. The largest individual refractive changes were those of myopes becoming more myopic. Since the initial refraction was at age 13, part of this increase in myopia may have been the continuation of childhood myopia progression before its cessation. None of the individuals who had 1.00 D. or more of hyperopia at age 13 became myopic.

Reports of Myopia Onset and Progression

Perhaps the earliest reports on myopia onset and progression were the ones by Derby

(1877a, 1877b, 1879, 1880, 1885). He did annual manifest (noncycloplegic) subjective refractions on four classes of students entering Amherst College. The 1879 paper reported results on the class of 1879, and the 1885 paper dealt with the classes of 1879, 1880, 1881, and 1882. Since the 1885 paper was more inclusive, its results are discussed here. The average age at the entrance exam was 19. Examined at entrance were 341 students, presumably all males; 254 were tested at the beginning and end of four years of school. His classifications of hyperopia and myopia included persons with 0.50 D. or more of the respective refractive error. At entrance, 125 (49.2 percent) of the 254 were emmetropic, 39 (15.4 percent) were hyperopic, and 90 (35.4 percent) myopic. At graduation, approximately four years later, only 87 (34.4 percent) were emmetropic, while 47 (18.5 percent) were hyperopic, and 120 (47.2 percent) myopic. Of the 39 cases who were hyperopic at entrance, 1 shifted into myopia (from +0.50 D. to −1.25 D.), 2 decreased in hyperopia, 27 remained stationary, and 9 increased in hyperopia. The average change in refraction over 4 years for the hyperopes was less than one hundredth of a diopter. Of the 125 initially emmetropic cases, 86 (68.8 percent) remained emmetropic, 10 (8 percent) became hyperopic, and 29 (23.2 percent) developed myopia. Of the 29 emmetropes who became myopic by the time of graduation, 20 (69 percent) developed 1.00 D. or less of myopia, and only 1 developed as much as 2.00 D. of myopia. Of the 90 myopes at entrance, 32 remained stationary, and 58 increased in amount. Of 58 myopic students who developed more myopia, 43 (74 percent) showed changes of 1.00 D. or less. The greatest change was one student with a shift of −2.50 D. The average change in refraction for the myopes was −0.569 D., which would represent a change of about −0.14 D./yr. There were both emmetropic and myopic students with changes in refraction toward myopia that were generally small in amount. Hyperopes tended to have stable refraction.

Parnell (1951) reported in a survey of undergraduate students in England that 31 (10.4 percent) of 297 men and 33 (18.6 percent) of 177 women had myopia at an initial health examination. Criteria for the definition of myopia were not given. Over a period of one year, Parnell reported a reduction in the number of eyes of undergraduates with 6/9 or better unaided visual acuity from 305 (59.3 percent) to 291 (56.6 percent) of 514 eyes (150 men and 107 women). Reasons for the reductions in unaided visual acuity were not given, but it can be assumed that a major one would be the appearance of myopia.

There are several studies in the literature that discuss the problem of individuals in military academies and military services becoming myopic. Hayden and Goss (1940) and Hayden (1941) observed that many of the candidates admitted to the U.S. Naval Academy with 0.25 or 0.50 D. of hyperopia or with very low degrees of myopia subsequently develop myopia of an amount sufficient to reduce visual acuity below the 20/20 level (unaided). Prior to 1937, the unaided visual acuity requirement for admission to the U.S. Naval Academy was 20/20 in each eye. Disqualifications for unaided visual acuity falling below 20/20 ranged from 14.14 to 31.46 percent of the classes of 1934 to 1940 during their four-year course (Hayden, 1941).

Hynes (1956) also investigated the records of men accepted to the U.S. Naval Academy. Refractive data were obtained by cycloplegic retinoscopy with 4 drops (1 drop every 5 minutes) of 4 percent homatropine. Of 1,419 men in the classes of 1949 and 1950 with spherical equivalent refractions of 0.50 D. or more hyperopia at entrance, only 36 developed myopia of any amount by graduation. There were 624 men with spherical equivalent refractive errors of +0.50 or less who had visual defects at graduation. A small number had refractions of −0.25 or −0.50 D. at entrance (four had a −0.50 D. refractive error). These 624 men were subdivided by age at entrance. In the 17-18-year-old age group, 91 (77 percent) of 117 had myopia (a negative spherical equivalent) at graduation; in the

19-year-old age group, 116 (44.4 percent) of 261 had myopia at graduation; for 20-year-olds, 66 (38.4 percent) of 172 had myopia; and in the 21-year-old age group, 11 (14.8 percent) of 74 had myopia. Not all of these refractions were done by the same examiner. Our analysis of his data suggests that 12.5 percent of these same 17- to 18-year-olds developed myopia of sufficient amount to be labeled as having "visual defect" at graduation. Hynes concluded that 17- and 18-year-olds with +0.50 or less spherical equivalent refractive error and 20/20 visual acuity were likely to develop myopia over the next four years.

Sutton and Ditmars (1970) documented an increase in the number of individuals requiring corrective lenses for 20/20 distance visual acuity during study at the U.S. Military Academy at West Point. Of the one class followed for all four years (class of 1969, N = 1,138), 49.2 percent required correction at the initial exam, 54.8 percent required correction one year later, 57.2 percent required correction two years later, and 60.4 percent required correction three years later. Although it is not specifically stated, one can assume that this increase is primarily due to more students' becoming myopic. For the class of 1970 (N = 965), a total of 45.5 percent, 53.7 percent, and 64.6 percent required optical correction for 20/20 visual acuity at entrance, one year later, and 2 years later, respectively. For the class of 1971 (N = 1,009), a total of 46.9 percent required correction at entrance and grew to a total of 60.0 percent one year later. At the time the Sutton and Ditmars study was conducted, the refractive error requirements for entrance into the U.S. Military Academy were: (1) not more than 5.50 D. of myopia or hyperopia in any meridian, (2) not more than 3.00 D. of astigmatism, (3) not more than 3.50 of anisometropia, and (4) visual acuity correctable to 20/20 in each eye. No statement was made concerning the effect of attrition on the results.

Greene (1970) presented manifest refractive error changes over four year of duty of Minutemen launch control officers. In a cross-sectional study of a total of 572 combat crew members, 84 cases were reported on the basis of having a change in refractive error. The pool for data selection was the 23 percent of spectacle wearers who showed an increase in negative refractive error. Of the 572, 363 (63 percent) wore spectacles. Initial refractive errors were not provided, but over 80 percent of the spectacle wearers were myopic. Combat crew members are college graduates between ages 22 and 38, and refractive errors at entry are limited to $\leq$ 5.50 D. of myopia and $\leq$ 3.00 D. of astigmatism. Visual acuity must be at least 20/400 correctable to 20/20, either eye. The launch control facility is a chamber approximately $15' \times 7' \times 9'$. Duty cycles are constituted of two 12-hour cycles with one intervening 12-hour rest period over a 7-day period, most of the alert duty time being spent doing near-point tasks. After the first year of duty, manifest refractions on 25 crew members who had changes in refraction showed an average dioptric shift of −0.58 D.; after two years, 27 crew members with changes in refraction showed a mean increase of −0.56 D.; after three years, 15 crew members shifted −0.75 D.; and after 4 years, 17 crew members showed a shift of −0.88 D. Reanalysis of the same set of data into age groups of comparable size yielded 24 subjects averaging 23.1 years of age, 21 subjects at 26.0 years, [illegible] 28.4, and 21 at 32.0. Mean shifts in refractive error relative to their entry level w[illegible] D., −0.64 D., −0.61 D., and −0.82 D., respectively, for those who did have shifts in refraction. These values did not differ significantly from each other(F [3, 82] = 1.86, $p > .05$). It is thus not likely that the significant increase in refractive error with year of duty was attributable to the increase in age with years of service. Though interpretation of this study is difficult, it suggests that about one-fourth (23 percent) of adults (mostly myopes) are likely to exhibit progressive increases in myopia in this type of environment with heavy near-work demands.

Gmelin (1976) presented frequency distributions of spherical equivalent refractive errors for the U.S. Military Academy class of 1974 at the entrance physical examination in 1970

and the commissioning examination in 1974. Refraction frequencies were given at 1.00 D. intervals (i.e., +3, +2, +1, plano, −1, ..., −9) with no further explanation. Of the 828 graduates, 423 (51.1 percent) had plano refractions (presumably −0.50 to +0.50) at entry, and 354 (42.7 percent) had plano refractions at graduations. At entry 362 (43.7 percent) were myopic, while at graduation 443 (53.5 percent) were myopic. Using Gmelin's frequency distributions for calculation, the mean refractive error at entry was −0.873 D., while at graduation it was −1.251 D. This is a mean change of −0.378 D., which would be a rate of change of −0.0945 D./yr., if the interval between exams was four years.

Kinney et al. (1974, 1980) presented a study of the visual characteristics of submariners. The longitudinal data were published in the 1980 report. Refractive data were manifest subjective refractions, with right eyes only used for analysis. Of 750 submariners originally tested, 160 were retested 3-4 years later. As a comparison group, 64 of 165 national guardsmen originally tested were retested 3.3 years later. Individuals who were still in the local area at the retest time were used in the longitudinal study. Attrition by reassignment or resignation was greater for the submariners than for the guardsmen. Distributions of refractive errors at the original test for those retested were similar to the entire original test groups for both submariners and guardsmen. The two groups were both stationed or living in the same area and consisted primarily (> 95 percent) of white males between the ages of 18 and 41 when first tested; they were similar in educational levels attained and time spent reading and watching TV. From questionnaire data it was determined that more submariners than guardsmen had hobbies that were primarily indoor near-work activities. Fairly high percentages of both submariners (39 percent) and guardsmen (48 percent) had changes toward myopia (see Table C-5). "More myopic" or "more hyperopic" were shifts of −0.25 D. or more and +0.25 D. or more, respectively. One-third or more of both submariners and guardsmen became more myopic at all three age levels, but comparable numbers of persons also showed more hyperopia at retest. Mean (± SD) changes in right eye spherical equivalent refractive error from test to retest were: for ages 22 to 29 at retest, submariners, −0.058 D. (± 0.542), guardsmen, −0.071 D. (± 0.303); for ages 30 to 37 at retest, submariners, +0.087 D. (± 0.790), guardsmen, −0.060 D. (± 0.487); for ages 38 to 45 at retest, submariners, +0.086 D. (± 0.224). Since these were mean changes over three- to four-year intervals, the mean annual changes would be quite small and would not show as much mean shift toward myopia as other age comparable groups discussed. It is interesting to note that, while there was no significant difference in refractive change between the submariners and the guardsmen, the submariners had significantly greater losses in amplitude of accommodation for 22- to 29-year-olds ($p < 0.03$) and 30- to 37-year-olds ($p < 0.001$). Measures of the time spent in submarines did not show a statistically significantly correlation with refractive error changes, nor did the men with myopic shifts greater than 0.25 D. in the 3.5 years differ in time spent in submarines from the others.

Brown (1986) compared the refractive error recording on cadets' vision survey card upon entry to the U.S. Military Academy with their refractive error at the beginning of their fourth year of study. Entry refractions were done by many different military and private practitioners. Refractions at the beginning of the fourth year were standard manifest refractions done by three military optometrists. A total of 418 cadets, all males, who represented about half the graduating class of 1979, were studied. They varied in age from 17 to 25. There were 147 fewer eyes in the 0 to +1.00 D. refractive error range for the fourth year data than there were in the entrance data. A total of 380 eyes did not require a spectacle prescription at entrance nor at the start of the fourth year. There were 93 eyes with no spectacle prescription at entry but that required one at the start of the fourth year. The average change for this group was −0.72 D. (SD = 0.83), which would be a

TABLE C-5 Refractive Error Change in Submariners and National Guardsmen

Age	Submariners N	Submariners %	National Guardsmen N	National Guardsmen %
22 to 29 at retest				
More myopic	22	49	9	43
No change	7	16	6	29
More hyperopic	16	36	6	29
Subtotal	45		21	
30 to 37 at retest				
More myopic	28	34	9	46
No change	16	19	7	28
More hyperopic	39	47	9	36
Subtotal	83		25	
38 to 45 at retest				
More myopic	12	37.5	9	90
No chanage	8	25	0	0
More hyperopic	12	37.5	1	10
Subtotal	32		10	
More myopic (total)	62	39	27	48
No change (total)	31	19	13	23
More hyperopic (total)	67	42	16	29
Total	160		56	

SOURCE: Kinney et al. (1980).

rate of about −.024 D./yr. The maximum change recorded was −2.12 D. and the minimum was −0.25 D. There were 3 eyes that changed in the hyperopic direction. There were 363 eyes in the category of having spectacle lenses both at entry and at the beginning of the fourth year; of these, 348 were myopic. There were 270 of the 363 eyes that had a change in refractive error, the average change being −0.55 D. (SD = 0.69), which would represent a rate of about −0.18 D./yr. The maximum myopic shift was −3.25 D., while the minimum was −0.12 D. There were 26 eyes with a change toward hyperopia. The average amount of myopic shift was greater for those who did not wear spectacles at entry (−0.72 D.) than for those who did (−0.55 D.). Brown also pointed out that a −5.50 D. eligibility limitation for entry to West Point appears to be reasonable, because it would be unlikely for a 5.50 D. myope to develop 8 D. of myopia (the limit for the commissioning of an officer) by the beginning of the fourth year.

In an unpublished study of the U.S. Air Force Academy class of 1980, Goodson (1983) compared the spherical equivalent refractive error taken at the beginning of the senior year with that indicated on the students' entering medical records. Data were spherical equivalents of the worst eye. Of 914 records, 225 reported refractive error, in addition to or instead of acuity. Of these, 196 or 76.9 percent showed a myopic shift of at least −0.25 D. over the three-year period, with a mean change of −0.83 D. in those who did have a myopic shift. Of the 86 cadets whose entrance refractive error fell within the acceptance region for Flying Class I (i.e., not exceeding +1.75 D. or −0.25 D.) 40 (46.5 percent) remained pilot-qualified on this standard.

A more recent unpublished study by O'Neal et al. (1986) was based on the Air Force Academy medical records of the class of 1985, of whom 89.3 percent were men. The data were spherical equivalent refractions of 497 records reported in terms of numbers of eyes. Omitted from the total possible number of class records (i.e., 944) were those absent on the day of data collection, those indicating use of near glasses or contact lenses, and incomplete entries. Entry-level refractions were performed by the individual's private vision specialist, and many or most probably were not taken under cycloplegia, but all those taken approximately two years later at the beginning of the third year of study were done by military optometrists and were taken after instillation of two drops of cyclopentolate. At entrance, 105 eyes (10.6 percent) were emmetropic, 409 (41.1 percent) were hyperopic, and 480 (48.3 percent) were myopic. Emmetropia was defined as a spherical equivalent of zero. At entry, 563 eyes (56.6 percent) fell in the range of +.050 to −0.50 D. Of the total number of eyes (994), 66.7 percent shifted in the myopic direction of −0.60 D. on average. Of the 514 emmetropic and hyperopic eyes on the entering record, 282 (54.9 percent) showed a shift in the myopic direction of at least −0.12 D. Of the 480 myopic eyes at entry, 381 (79.4 percent) progressed in the myopic direction of at least −0.12 D. On average over the two-year period, the change in refraction equalled −0.18 (± 0.42) D. for the emmetropic eyes, −0.18 (± 0.37) D. for the hyperopic eyes, −0.54 (± 0.62) D. for the myopic eyes, and −0.34 (± 0.53) D. for the total. At the time of the second exam, 32.8 percent of eyes were hyperopic, 10.9 percent were emmetropic, and 56.3 percent were myopic. For persons having a shift toward myopia, the average shift was −0.60 D. Of the 612 eyes whose entering refractions fell within the Flying Class I standard, 506 (82.7 percent) remained pilot-qualified.

Provines et al. (1983) reported a survey of 1,105 navigators and 1,295 pilots stratified by major air commands. The study provided a random sample of the number of pilots and navigators required to wear corrective lenses and of initial and current spherical equivalent refractive errors. The study included persons who had entered undergraduate training at ages 20 to 25 and who had served on active duty for 20 years or less. Myopia was defined as a spherical equivalent refractive error of more than −0.25 D. In analyzing the number of

TABLE C-6 Pilots and Navigators Who Developed More Than 0.25 D. of Myopia by Various Initial Refractive Error Levels

Initial spherical equivalent refractive error	N	Did Not Become Myopic (0.25D. or more)	Did Become Myopic (0.25D. or more)
Pilots:			
-0.25 to plano	248	205	43 (17.3%)
+0.12 to +0.37	251	231	20 (8.0)
+0.50 to +0.75	193	191	2 (1.0)
> to +.87	100	100	0 (0.0)
Total	792	727	65 (8.2)
Navigators:			
-0.25 to plano	153	109	44 (28.8)
+0.12 to +0.37	142	132	10 (7.0)
+0.50 to +0.75	119	112	7 (5.9)
+0.87 to +1.12	31	29	2 (6.5)
> +1.25	16	16	0 (0.0)
Total	461	398	63 (13.7)

SOURCE: Provines et al. (1983).

persons initially hyperopic who became myopic, three trends are apparent: (1) navigators were more likely to become myopic: 65 (8.2 percent) of 792 pilots became myopic, compared with 63 (13.7 percent) of 461 navigators. (2) The incidence was more likely in persons who had greater time in service. For example, among persons with 1 to 5 years of service, 2.4 percent of pilots and 7.8 percent of navigators had become myopic. This can be compared with 17.6 percent of pilots and 24.7 percent of navigators who became myopic during 16 to 20 years of service. (3) As Table C-6 indicates, both pilots and navigators were more likely to develop myopia if the initial refraction was near plano. The highest incidences were for persons with initial refractions of −0.25 D. to plano.

Shotwell (1981, 1984) has studied the effects of reading lens prescription on refractive error changes in young adults. In a 1981 report, he randomly assigned 232 students in the

Naval Academy Preparatory School (ages 18 to 20) to one of three reading prescription groups: (1) distance correction with no. 1 pink tint (placebo group); (2) +1.25 D. added to the distance correction with two prism diopters base-in over each eye; (3) bifocals with a +1.50 D. added. There was a very high rate of attrition in the study: 100 subjects did not wear their spectacles when reading and were not included in the analysis, and 44 subjects disenrolled or were not available for retest. Only persons with refractive errors between +1.00 D. and −1.00 D. initially were used in the statistical analysis. This left 21 subjects in the placebo group, 20 in the plus and prism group, and 19 in the bifocal group. The mean changes in each group were not significantly different from zero.

Shotwell followed 61 of these students for an additional four years spent at the U.S. Naval Academy. The primary cause of the attrition was disenrollment at the Academy (116 subjects); other causes were failure to wear the lenses full time for reading (40 subjects) and voluntary withdrawal (18 subjects). These 61 subjects had initial refractive errors between −0.37 D. and +0.75 D. (mean = +0.22; SD = 0.43). The subjects were predominantly white with a mean age at the start of the study of 18.7 years (SD = 1.3; range = 17 to 21 years). The three types of lens prescriptions were the same as in the 1981 study. Pre- and post-test refractions were done using 1 drop of 1 percent tropicamide, with the examiner blind to the subject's group assignment. The mean refractive changes in four years were: (a) placebo group, −0.23 D. (n = 21; SD = 0.28); (b) plus with prism group, −0.27 D. (n = 27; SD = 0.27); (c) bifocal group, −0.15 D. (n = 13; SD = 0.37). These means were not significantly different. The control group had a mean rate of change that was about −0.06 D./yr. Shotwell also divided the 21 subjects in the control or placebo group into 10 in "high-risk" groups and 10 in "low-risk" groups according to six theoretical risk factors for changes toward myopia: number of family members wearing glasses, near-point cover test phoria, cup-to-disk ratio, reading distance, reading style (deliberate versus fast), and time spent on near work versus time spent in outdoor activities. Of the six risk factors, only the time spent on near work versus time spent outdoors showed a statistically significant difference in mean refractive change between the high-risk and low-risk groups. While this study was well designed and executed, the high attrition rate is a considerable limitation.

Diamond (1957) reported a study of 67 airline pilots whom he followed for employment periods of time ranging from 5 to 18 years, all of whom had 20/20 unaided visual acuity at the time of employment. For the 16 pilots who became myopic enough to reduce unaided visual acuity or worse, the ranges of ages and refractive errors at the beginning of employment were 21 to 31 years and −0.25 to +0.25 D. The spherical equivalent refractive error shifts ranged from −0.25 to −1.25 D. (mean, −0.65 D.) over periods of time that varied from 5 to 17 years (mean, 12.3 years). Diamond stated that the development of the myopia was slow and gradual over the years of observation. The average annual change was −0.05 D. for the 16 who became myopic. Individual myopic shifts as a function of initial age and length of employment are depicted in Figure C-3. Although the number of persons in each initial age category was not over four, the mean rates of change were similar in each category. The 51 pilots who did not move into myopia were 20 to 30 years old initially, had refractive errors of −0.25 to +2.25 at the beginning of their employment, and were followed for 9 to 18 years.

Dunphy et al. (1968) discussed refractive error changes in 100 graduate students ages 20 to 30 (200 eyes) enrolled in the Harvard business and law schools. At annual visits, cycloplegic refractions were done 15 minutes after the instillation of 2 drops of 1 percent tropicamide five minutes apart. Refractive errors were analyzed in terms of spherical equivalents. In most cases, data was expressed in terms of number of eyes rather than number of persons. The study group of law students had a greater proportion of students with uncorrected acuity of 20/20 or better than their entire class (more than 50 percent

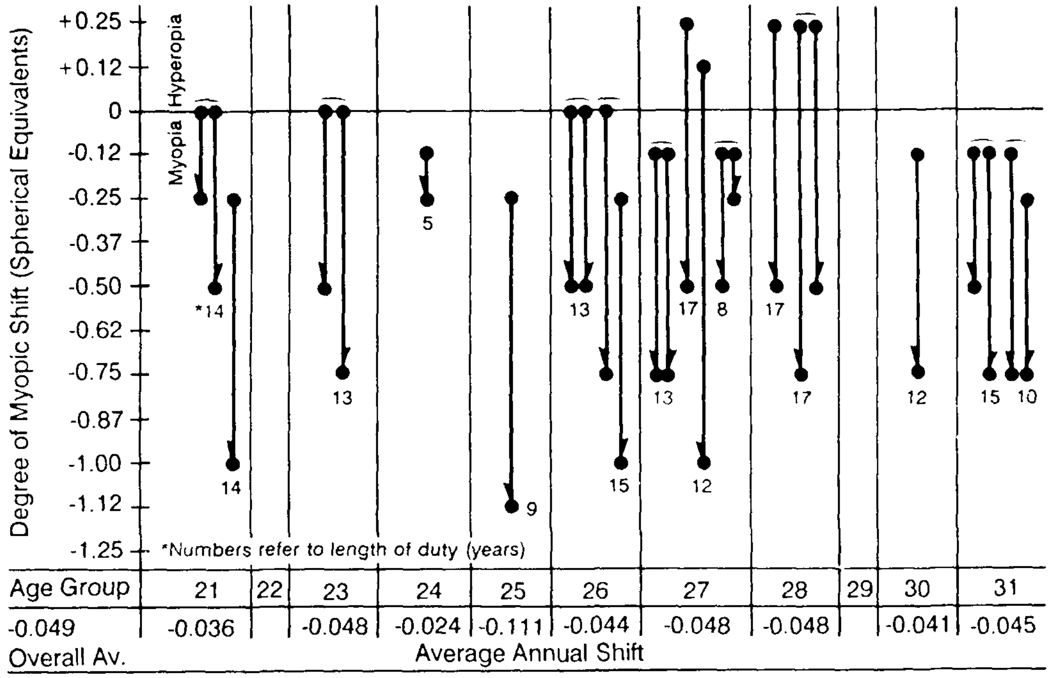

FIGURE C-3 Refractive error changes in individual pilots who developed myopia according to age at beginning of employment and length of employment. The brackets indicate the two eyes of one individual. Beginning and ending spherical equivalent refractive errors are represented by dots.

Source: Adapted from Diamond, 1957.

compared with 39 percent). The changes in one year and the corresponding numbers of eyes were: +0.50 to +0.25 D., 29 eyes; +0.125 to −0.125 D., 89 eyes; −0.25 to −0.50 D., 73 eyes; and −0.625 to −0.875 D., 9 eyes. All 9 eyes in this greater negative change category were myopic (amount unspecified) at the beginning of the study. Of 40 law students followed for a second year, 40 of the 80 eyes changed −0.25 to −1.50 D. in two years. Of these 40 students, the 24 students with initial refractions of −0.125 to +1.50 D. had a mean change in two years of −0.12 D., 11 students with −0.75 to −0.25 D. refractions averaged −0.47 D. change in two years, and 5 students with −5.25 to −2.00 D. refractions averaged −0.01 D. change.

Kent (1963) presented six case reports of myopia onset at age 18 or later. Some of the recorded refractions were done under cycloplegia and some were not. The means of the spherical equivalents of the two eyes were used for analysis. Excluding one case due to lack of complete data, the rates of refractive error change of the remaining five varied from −0.04 to −0.16 D./yr. over time spans varying from 9 to 26 years. The myopia developed was all low in degree and generally developed over a period of several years. In another case, keratometer measurements were taken on several occasions. There were increases in spherical equivalent keratometer powers of 0.58 D. in the right eye and 0.65 D. in the left eye, corresponding to spherical equivalent refractive error changes of −0.94 D. in the right eye and −0.75 D. in the left eye. It would appear that this subject's myopia developed largely as a result of an increase in corneal power. Kent stated that three subjects first manifested myopia while they were students, but that most of their myopia developed after completing school, and that three other subjects "were not engaged in activities requiring

much close work when their myopia developed." He also noted that two subjects in the first group and one in the other each observed transient distance blur occurring after prolonged nearwork just prior to their myopia onset. This study is notable in that it is apparently the first to report changes in an ocular component in adult myopia progression.

Goss et al. (1985) studied young adult myopia progression the same optometry practice population of 559 subjects used by Goss and Cox (1985). The refractive error data consisted of the refractive error in the principal meridian nearest horizontal in the right eye. Goss et al. reported three analyses: (1) subjective categorization of patterns of refractive error change typical of young adulthood in myopes; (2) rates of refractive error change; and (3) changes in keratometer readings. There was a sufficient number of data points for subjective categorization of young adult patterns for 63 males and 53 females. The majority of subjects, 68.3 percent of males and 86.8 percent of females, fit the pattern they termed adult stabilization, characterized by rapid increase in myopia in childhood and adolescence, followed by stabilization in adulthood. Adult continuation was found in 25.4 percent of the males and 13.2 percent of the females in the sample. It is characterized by myopia progression in adulthood, but at a slower rate than that during childhood. The least common pattern (6.3 percent of males and none of the females) was adult acceleration, in which myopia progression accelerates in adulthood. In this category they included cases both of acceleration of existing myopia and the adult onset of myopia. It may be noted that patterns with refractive changes toward myopia were more common among males (see Figure C-4). They calculated rates of young adult myopia progression, using linear regression slopes (D./yr.) for the 57 cases with 3 or more data points at age 20 and later, and separately for the 108 cases with 3 or more data points at age 18 and later. Most of the records ended in the middle 20s, but some continued to the middle 30s. The mean rates for age 20 and over were −0.07 D./yr. (SD = 0.09) for males and −0.03 D./yr. (SD = 0.09) for females, while for age 18 and over they were −0.08 D./yr. (SD = 0.11) for males and −0.02 D./yr. (SD = 0.06) for females. The difference in mean rates for males and females was statistically significant for both age criteria ($p < 0.05$ for age 18 and over and $p < 0.01$ for age 20 and over). The rates for age 18 and older ranged from +0.19 to −0.25 D./yr. for females and from +0.09 to −0.36 D./yr. for males. Low negative rates appeared to be most common. For 11 subjects in the adult stabilization and adult acceleration categories and 20 subjects in the adult continuation category, Goss et al. (1985) had data on three or more refractions and three or more keratometer measurements recorded at age 18 and beyond. For the keratometer readings, like the refractions, the principal meridian nearest horizontal in the right eye was used for analysis, and rates were calculated by linear regression analysis. For all 11 of the adult continuation and adult acceleration subjects with three or more keratometer readings, there was a reduction in the corneal radius (range of rates, −0.003 to −0.042 mm/yr.), which would cause a shift toward myopia. The coefficients of correlation of corneal radius with refractive error for these 11 subjects varied from +0.12 to +0.98, based on an average of only 3.9 points per subject. For the 20 adult stabilization subjects, there were 11 increases in corneal radius and 8 decreases, most of them small in amount and with rates ranging from +0.014 to −0.036 mm./yr. Data on other ocular dioptric components for this sample were not available.

Goss and Erickson (1987) reported a further analysis of the relation of refractive error and corneal power changes in their sample to assess the contribution of corneal changes to myopia progression. For analysis they selected the records with three or more refractions and three or more keratometer readings at age 18 or later: 22 males and 15 females met this criterion. Right eyes were used for analysis. Most records stopped at about age 25. Rates of refractive error change and rates of keratometer power change were

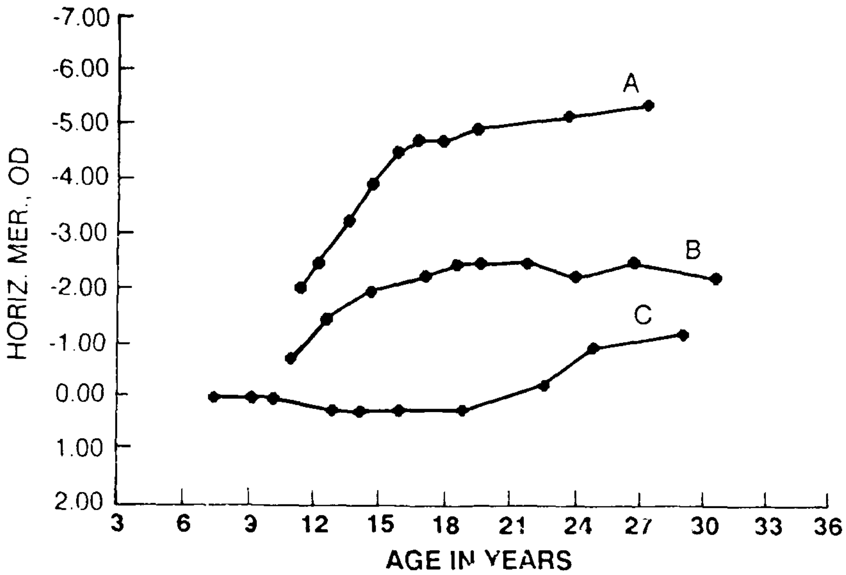

FIGURE C-4 Examples of young adult myopia progression patterns based on the classification system of Goss et al., 1985. Each set of common symbols represents refractive data for one subject: A—adult continuation; B—adult stabilization; C—adult acceleration.

Source: Adapted from Goss and Cox, 1985.

calculated by linear regression. Statistically significant correlations were found between rate of refractive change and rate of keratometer power change for young adult myopia progression. (Significant correlations were not found for childhood myopia progression.) The regression slopes of refractive error change (y) on keratometer power change (x) were around 0.7. This slope is close to the 0.68 slope found by Erickson and Thorn (1977) for corneal changes in orthokeratology, and it indicates that across the sample, about two-thirds of a diopter change in keratometer power results in one diopter shift in refraction. Non-zero y-intercepts in the regression equations may be due to the effects of other components or to corneal changes not measured by the keratometer (Erikson, 1978). These findings indicate that the cornea can play some role in the progression of myopia in young adults, but the contribution of other ocular components cannot be ruled out.

Adams (1987) reported a case in which adult myopia progression was apparently not primarily due to corneal steepening. From ages 24 to 42 the manifest refraction showed changes of −3.75 D. in each eye in the principal meridians nearest horizontal and −3.25 D. in each eye in the principal meridians nearest vertical. The corresponding changes in keratometer power were: horizontal, +0.75 D. in the right eye and +1.00 D. in the left eye; vertical, +0.25 D. in the right eye and +0.37 D. in the left eye. In unpublished theses, Schell et al. (1986) reported that most of the adult myopic shift found in a group of optometry students could be accounted for by axial length changes, and McBrien (1986) found that axial elongation accounted for myopic changes in his young adult sample.

On the basis of observations that the rates of increase of myopia typical of youth are different from those in adulthood and that the mechanisms associated with each may be different, Goss has proposed that different terminology should be applied to the two phenomena. He and his colleagues have referred to the increases in myopia preceding the middle to late teens as childhood myopia progression and any increases subsequent to that as young adulthood myopia progression. After the cessation age of childhood myopia

progression (Goss and Winkler, 1983), refraction may either be stable or may show young adult myopia progression. Some emmetropic young adults also have myopia appear with subsequent young adult myopia progression. As discussed in the next section, the rates of adult myopia progression following adult onset are different from those of childhood myopia progression.

CHANGES IN DIOPTRIC COMPONENTS OF THE EYE

Sorsby et al. (1961) presented both cross-sectional and longitudinal data. In the cross-sectional study were 1,432 children (671 boys and 761 girls) ages 3 to 15 drawn from London County Council schools and day nurseries in South London. About 30 to 40 percent of those contacted volunteered for the study. Refractive error was determined by retinoscopy under scopolamine cycloplegia, and corneal power by keratometer. Anterior chamber depth and lens thickness were calculated from slit lamp cross-sectional photographs. Radii of curvature of the crystalline lens were derived from comparison phakometry. Axial length was calculated using the above information. Over the age span studied (ages 3 to 14 in boys and ages 3 to 15 in girls), the mean vertical meridian refractive error shifted toward less hyperopia by 1.40 D. in boys and 2.30 D. in girls. Between ages 3 and 13, mean axial length increased about 1 mm for both boys and girls, and mean crystalline lens power decreased a little less than 2 D. Changes in mean corneal power were slight.

The longitudinal study in the Sorsby et al. monograph consisted of 440 subjects, who were reexamined 2 to 6 years after the initial test; 54 cases were excluded due to inconsistencies in findings, leaving 386 cases (183 boys and 203 girls). In 135 cases (34.9 percent) axial length increased 0.0 or 0.1 per year. In these cases, refractive errors and cornea and lens also tended to be close to stationary. In 195 cases (50.5 percent) there was a yearly axial length increase of 0.2 or 0.3 mm. Sorsby et al. noted that, if uncompensated by other components, this would cause a shift toward myopia of 0.6 to 0.8 D. Only 13 of these 195 (6.7 percent) had refractive changes of this order. Most of the children had full or partial compensation for this axial elongation by reductions in corneal or lens power. The remaining 56 cases (14.5 percent) showed an annual axial elongation of 0.4 mm or more. There was considerable variability in the corresponding changes in refractive error: 12 of the 56 (21.4 percent) showed adequate compensation (refractive error changes of 0.0 to 0.2 D./yr.); 24 of the 56 (42.8 percent) had annual refractive changes of 0.3 to 0.5 D; and 20 of the 56 (35.7 percent) shifted toward myopia by 0.6 or more per year. For those children first examined at younger than 10 years of age, the numbers with the higher and lower levels of axial elongation were approximately equal for all beginning refraction categories (myopia, emmetropia, and mild and severe hyperopia), but higher amounts of axial elongation predominated for children who became myopic. For subjects first tested at 10 years of age or older, there were proportionately more cases of higher axial elongation among those who were myopic or became myopic. That is, among the older children, 10 of 83 (12 percent) of the hyperopes showed marked axial elongation, compared with 15 of 43 (34.9 percent) of the emmetropes, 6 of 14 (42.9 percent) of the myopes, and 7 of the 17 (41.2 percent) who became myopic.

In a later monograph, Sorsby and Leary (1970) discussed follow-up observations of 129 children in the 1961 study, using the same examination methods: 68 of these children had the follow-up examination at or before age 14. They divided these 68 cases into 49 with slight shift toward myopia ($\leq$ 1.31 D. in an average of 8.25 years) and 19 with greater shifts ($>$ 1.51 D.). The group with higher refractive shifts showed greater axial elongation but similar amounts of corneal and lens power decrease. In general, the greater the axial

elongation, the lower the corneal and lens power. However, adequate compensation does not occur in some subjects, so that the mean refractive shift toward myopia increases as the amount of axial elongation increases. There was great individual variability in refractive error and component changes. The work by Sorsby and his colleagues suggests that myopia appears and childhood myopia progression occurs most often when axial elongation is greater than usual or when average amounts of axial elongation are not adequately compensated for by corneal and lens power reductions.

Tokoro and Suzuki (1968, 1969) measured the refractive components of 56 eyes over the time span of 1960 to 1967: 33 eyes in 18 subjects were examined four times, and 23 eyes in 13 subjects were examined two or three times. The subjects ranged in age from 7 to 21 in 1960. Refraction was determined 24 hours after the instillation of two drops of 1 percent atropine. The radius of curvature of the anterior surface of the cornea was measured by ophthalmometry. Anterior chamber depth and crystalline lens thickness were determined by Jaeger's apparatus (Duke-Elder and Abrams, 1970). Radii of curvature of the crystalline lens were found by photographic phakometry. Axial length was determined by calculation and by ultrasonography, but it was unclear which was used in the analysis. Refractive index and power of the crystalline lens were derived by calculation.

Tokoro and Suzuki found significant correlations of refraction, lens power, and axial length at the initial examination with the annual change in refraction. They also calculated average changes in refractive components according to age (see Figure C-5). There was little change in corneal power at any age. There was some reduction in lens power up to age 11 or 12, which would partially compensate for the axial elongation that occurs at this time. Most obvious is an increase in axial length. This axial elongation is greatly diminished after age 17 or 18. Plots by Tokoro and Suzuki of individual change in refractive error with age and plots of axial length versus age show remarkably similar patterns of increases until the middle or late teens, followed by a plateau or period of less change. Such a comparison might lead one to suggest that the cessation of childhood myopia progression could correspond to the cessation of axial elongation of the globe.

In 1971, Larsen reported a major cross-sectional study of the ocular components in children conducted in Norway (Larsen 1971a, 1971b, 1971c): 80 full-term newborns (43 boys, 37 girls) were examined with 0.2 percent oxibuprocaine or tetracaine without cycloplegia. For children of ages 6 months to 7 years, a general anaesthetic was used with cycloplegia (1 percent cyclopentolate HCL). In the age groups 8 to 13 years, surface analgesia was used with cycloplegia. There were 465 boys and 381 girls, excluding newborns. Larsen (1971a) points to three phases in the development of anterior chamber depth dimensions: (1) rapid postnatal growth phase from birth to one and a half years, with anterior chamber depth increases of approximately 0.9 to 1.0 mm in both sexes; (2) a slower infantile growth phase from 1 to 7 years, with increases of approximately 0.3–0.4 mm; and (3) a slow juvenile growth phase from 8 to 13 years, with an increase of 0.1 mm. No difference was found between the values for the anterior chamber depth at age 13 and the values for 20 emmetropic adults in he age group 20 to 40 years. Negative correlations of anterior chamber depth and refractive error (deeper anterior chamber in myopes) were found from the second year of life onward. For 76 eyes of 12-year-old girls, this correlation was $r = -0.88$ (Larsen 1971a).

In 80 newborns, Larsen (1971b) found that the mean value of the lens thickness taken with cycloplegia was 3.93 mm in 43 boys and 3.99 mm in 37 girls. Lens thickness decreased to 3.36 mm in 12 boys and 3.45 mm in 24 girls in the 13-year-old age group. The drop was consistent through the entire age range. For both boys and girls, since the drop was obtained with the application of cycloplegia in the age range 1 to 13, it was not an artifact

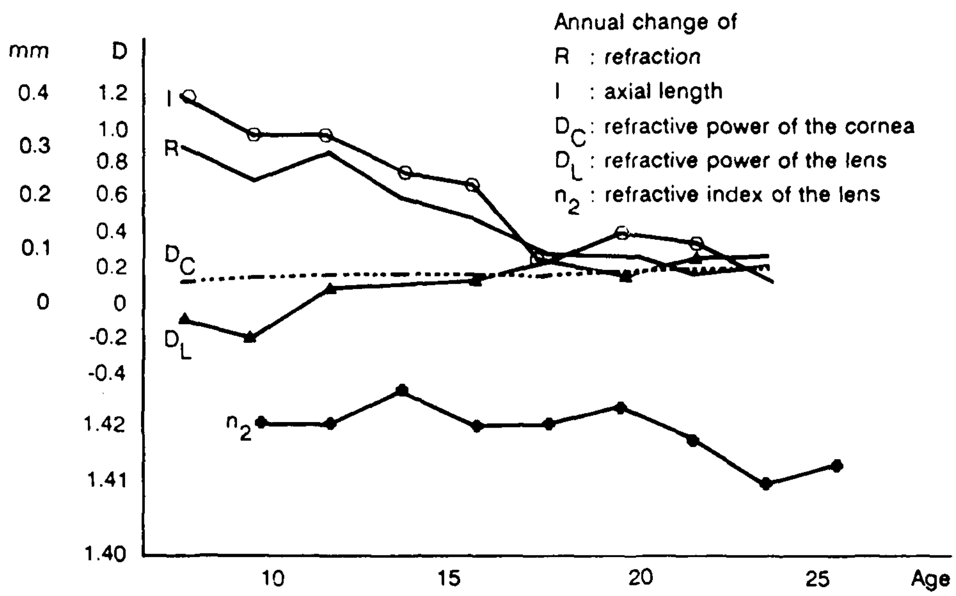

FIGURE C-5 Average annual changes in refractive components with age.

Source: Adapted from Tokoro and Suzuki, 1969.

of the absence of cycloplegia in the newborns. No correlation was found between refractive status and lens thickness or between lens thickness and anterior chamber depth. Larsen (1971c) also reported that vitreous depth averaged 10.48 mm and 10.22 mm in the male and female newborns, respectively. Comparable values at one year were 13.62 and 13.24, showing major growth during this period. For years 10 to 13, males averaged 15.62 mm, females 15.31 mm. These levels closely approximated those of 10 emmetropic men (15.44 mm) and 10 emmetropic women (15.18 mm). The relation between the ametropias and vitreous length was reported for the 1- to 3-year-old age group, separately for boys and girls. For the 20 male myopic, 86 emmetropic, and 158 hyperopic eyes, the vitreous measured 14.13 mm, 14.04 mm, and 13.72 mm, respectively. The corresponding values for the 8 female myopic, 106 emmetropic, and 102 hyperopic eyes were 14.24 mm, 13.86 mm, and 13.67 mm. For 12-year-old girls (76 eyes), the coefficient of correlation of vitreous depth and refractive error was −0.88. Considering the total axial length of the eye (i.e., the sum of the anterior chamber depth, axial diameter of the lens, and the length of the vitreous), Larsen (1971a) suggested three growth periods: (1) a rapid postnatal phase with an increase in length of 3.7 to 3.8 mm in the first year and a half; (2) a slower infantile phase from the second to the fifth year of life, with an increase in length of 1.1–1.2 mm; and (3) a slow juvenile phase continuing to age 13, with an increase of 1.3 to 1.4 mm. Most of the increase in axial length is an increase in vitreous depth. Larsen (1971d) also noted that the greater the myopia, the greater the axial length. For 12-year-old girls, the coefficient of correlation of axial length and refractive error was −0.82.

Fledelius (1980, 1981a, 1981b, 1981c, 1982a, 1982b) reported on the follow-up at age 18 of 137 of 539 persons who were originally examined at about age 10 to assess the ophthalmic risks associated with premature birth (as defined by low birthweight, < 2000 g). The follow-up sample consisted of 70 persons who were born with low birthweight (LBW group) and 67 who were born full term (FT group), and it deliberately overrepresented myopes (n = 58) due to the selection criteria used. Of the LBW group, 52.9 percent were myopes

TABLE C-7 Refraction and Axial Length and Their Changes from Ages 10 to 18 in a Sample of Low Birthweight and Full-Term Subjects

	N	Av. ref. error at age 18 (D.)	Change in refractive error from age 10 to 18			Average axial length at age 18 (mm.)	Change in axial length from age 10 to 18		Mean age at exam (yrs.)	
			Mean	SD	Range		Mean	Range	Initial	Follow-up
LBW males	36	-2.2	-1.75	1.66	0 to -6.3	24.23	0.90	-0.17 to +2.67	10.0	18.3
FT males	36	-0.2	-1.26	1.23	+0.2 to -4.3	24.19	0.73	-0.22 to +2.19	10.3	18.4
LBW females	34	-0.9	-1.29	1.03	0 to -4.0	23.38	0.64	-0.29 to +1.92	9.8	18.2
FT females	31	-0.6	-1.07	0.91	+0.5 to -3.8	23.73	0.48	-0.11 to +1.99	10.7	18.6

Note: LBW = low-birthweight group; FT = full-term group

SOURCE: Fledelius (1980, 1981a, 1981b).

and, of the FT group, 31.3 percent were myopes. It was estimated that, if the entire initial group of 539 had been followed up at age 18, 17.6 percent of the LBW group and 13.1 percent of the FT group would have been myopes (Fledelius, 1980). Corneal curvature was measured by keratometry; anterior chamber depth, lens thickness, vitreous depth, and axial length were determined by ultrasonography. Refraction values were spherical equivalents from retinoscopy with 1 percent cyclopentolate and 1 percent cyclopentolate and 1 percent tropicamide. Right eyes of the 137 subjects were used for analysis, along with 20 left eyes of anisometropes in the sample.

Fledelius (1980, 1981b) noted that of the 137 subjects, 127 had a change in refractive error toward myopia, with the range being from +0.50 to −6.25 D. change between ages 10 and 18. The refractive error changes were generally greater in myopes (median change, −1.70 D.) than in emmetropes and hyperopes (median change, −0.70 D.). Among both males and females, LBW subjects had a more myopic mean refractive error, a more negative mean change in refractive error, and a greater mean axial elongation (see Table C-7). The differences may in part be due to selection factors, since there were proportionately more myopes in the LBW group. The most noticeable ocular dioptric component alteration was an axial elongation (see Table C-8). Axial elongation was especially prominent in the eyes with greater changes in refractive error.

Fledelius (1981a, 1981b) noted that for comparable refractive error levels, LBW subjects had lesser corneal radii of curvature and shorter axial lengths than FT subjects. Fledelius (1981c) also distinguished between a "myopia of prematurity" and a "juvenile myopia" in the LBW group on the basis of onset age. He characterized myopia of prematurity as being diagnosed in infancy or the preschool years, of high amount, and rather static, compared with juvenile myopia as appearing around ages 8 to 15 and progressing thereafter to generally low or medium amounts. Both LBW categories show a small corneal radius of curvature ("steep" cornea). Premature birth is a risk factor for myopia development early in life, but it is unclear whether it is a risk factor for myopia development in later periods.

TABLE C-8 Mean Refractive Error Change and Ocular Dioptric Components at Age 18 in a Sample of Low-Birthweight and Full-Term Subjects

	N	Refractive error (D.)	Corneal radius of curvature (mm.)	Anterior chamber depth (mm.)	Lens thickness (mm.)	Axial length (mm.)
LBW males	36	-1.75	-0.004	+0.08	+0.03	+0.90
FT males	36	-1.26	+0.02	+0.17	-0.02	+0.73
LBW females	34	-1.29	-0.005	+0.08	-0.01	+0.64
FT females	31	-1.07	+0.003	+0.09	-0.02	+0.48

Note: LBW = low-birthweight group; FT = full-term group.

SOURCE: Fledelius (1981b, 1982a)

COMPARISON OF RATES OF MYOPIA PROGRESSION FOR ADULT- ONSET AND CHILDHOOD MYOPIA

The rates of young adult myopia progression after onset in adulthood are lower than the rates of childhood myopia progression. In the Derby study (1985), of the 29 emmetropes at college entrance who became myopic by graduation, 20 (69 percent) developed 1.00 or less myopia, and only 1 developed as much as 2.00 D. of myopia. Thus, the majority were progressing at a rate of −0.25 D./yr. or less minus. In the Diamond study (1957), the 16 airline pilots who became myopic had an average annual change of −0.05 D. For five adult-onset myopes followed by Kent (1963), the rate of refractive change varied from −0.04 to −0.16 D./yr. In the Goss et al. report (1985), three of the four patients classified as adult acceleration types were adult-onset myopes, and all were males. These three had rates of young adult myopia progression of −0.16, −0.13, and −0.04 D./yr. Based on tabular data in the O'Neal report (1986), there were 51 emmetropes (spherical equivalent equal to zero diopters) who became myopic in their first two years at the Air Force Academy. Of these cadets, none developed more than 1.50 D. of myopia; the mode was 0.25 D. of myopia. The average change was −0.49 D. for a rate of about −0.25 D./yr. For comparison purposes, one can look at the rates of childhood myopia progression from Mantyjarvi (1985b) and from Goss and Cox (1985). Mantyjarvi found a mean rate of childhood myopia progression of −0.55 D./yr. in Finland. Goss and Cox found a mean rate of −0.40 D./yr. for boys in the central United States.

Appendix D
The Etiology of Myopia

Although our review was not directed toward studies specifically addressing etiology or the evaluation of etiological theories, it is difficult to avoid their consideration: not only are such theories proposed by many of the authors whose articles were reviewed, but they also provide a structure within which to organize the many observations encountered. Moreover, etiological theories have important implications both for future research and for clinical management. Thus, while a rigorous review of etiological theories is beyond the scope of this report, we mention the more prominent theories and how they refer to observed prevalence patterns.

The use of myopia prevalence data to address etiology has two serious limitations. First, etiology is concerned with the *development* of a condition and is most directly addressed by incidence rates in longitudinal studies. Prevalence, which measures the proportion of people who are myopic at a given time, is affected not only by the incidence (development) of myopia experienced by a population, but also by persistence of the condition and longevity of individuals with myopia. Furthermore, when there is an observed relationship of myopia prevalence with other subject characteristics (risk factors), it is not always possible to determine which preceded the other. Thus, prevalence data must be interpreted with special caution. Second, since an individual's refraction results from the combination of several ocular components, an understanding of the variation and coordination of these components is essential to an understanding of myopia etiology. Articles concerning both incidence and ocular components are mentioned in relation to etiological theories but neither has been systematically reviewed for this appendix.

TYPES OF MYOPIA

It is a widespread view that myopia is not a single condition but several different etiological and possibly physiological entities. There is, however, no clear agreement about what distinctions should be made and how the different types of myopias would best be defined and recognized. Many of the distinctions in effect separate the more severe from the less severe myopias. This distinction may be made in terms of refractive error (severe versus mild myopia) or the presence of axial elongation outside the range found in emmetropes ("axial" versus "correlational" myopias). An early argument that the severe myopias represent a separate entity from the milder myopias was based on the observation of the skewed shape of the refraction curve. It had been observed that the refraction

curve becomes essentially symmetrical when the more severe myopes, or individuals with other pathological ocular changes, are removed from the population—suggesting that these individuals represent a separate population. This argument is supported by the observation that severe myopia has different patterns of distribution than mild and moderate myopia. Severe myopia is more likely to be associated with a variety of other problems, such as prematurity, infectious disease, etc., and seems likely to appear at a much earlier age than the milder forms. Goldschmidt (1968) noted that, unlike myopia in general, severe myopia appears to be equally prevalent in all occupational categories and appears to have decreased in prevalence from the 1880s to the 1960s in Denmark. Goldschmidt suggested a negative error of 6 to 9 D. as the limits of the range of severe myopia.

Sorsby et al. (1957) proposed that failure in the correlation of the optical components resulting in correlational myopia should be considered an aberration of emmetropia. They further porposed that, although the view that myopia is due to an abnormally long eyeball is valid, this validity is limited to refractive errors outside the range of those caused by faulty correlation of normal optical components. More modern statistical analyses suggest axial length is equally well correlated at all refractive errors (Gernet, 1964).

In summary, despite differences in views as to what particular distinction should be made, there appears to be general agreement that very severe myopia represents a separate entity from low and moderate myopia.

Goldschmidt (1968) also suggested that a distinction should be made between myopia developing during school years and stabilizing in the third decade and myopia that is seen in specific occupations, appears to develop at a later age, and does not stabilize but rather continues to progress with continued work in that occupation (i.e. childhood- versus adult-onset myopia).

GENETIC COMPONENT OF ETIOLOGY

The few genetic studies that were included in the articles summarized suggest a genetic component to the etiology of myopia, although no specific mode of inheritance was specified. Goldschmidt (1968), after reviewing the literature and presenting his own data, concluded that mild myopia is probably polygenic, while the severe myopias represent a heterogeneous group, some types of which may follow a monogenic mode of inheritance. The report of an association of myopia with consanguinity also suggests a genetic role in the etiology of myopia. The observation of racial differences in myopia prevalence may be due to genetic differences but may also be due to cultural differences. A continued high rate of myopia upon migration, as with the Asian groups in Hawaii, supports a genetic role, although cultural differences in ethnically defined subpopulations are certainly possible. However, it is difficult to explain observed trends in myopia, such as those believed to have occurred among the Eskimos and American Indians by postulating major genetic changes over such a short period of time.

The important point, however, is that genetic and environmental etiologies are not mutually exclusive—a point that does not appear to have been appreciated by many early authors, who refute one by providing evidence supporting the other. Whereas understanding the genetic role in the etiology of myopia is of interest, it may be of more practical importance to pursue an understanding of the environmental causes of myopia and their relative importance in various populations and to identify possible means of intervention.

ENVIRONMENTAL THEORIES OF MYOPIA ETIOLOGY

Near Work

The near-work theory postulates that myopia is caused by certain near visual activities, including reading. Evidence consistent with this hypothesis includes high rates in cultural groups with high literacy; an association of myopia with educational level, amount of time spent reading, and near work; and reports linking increased myopia with the introduction of schools into a population.

Those disagreeing with the near-work hypothesis suggest that myopes tend to read more than nonmyopes because of their myopia, giving rise to the observed association (see, for example, Ashton, 1985). Studies claiming to refute this explanation show that myopic children tended to be readers before their myopia developed, presumably establishing the directionality of the association. There is an unstated assumption in this argument, however, which is that future myopes are refractively the same as future nonmyopes. This assumption is contradicted by longitudinal studies. For example, Hirsch (1964b) followed 383 children and observed that refraction at age 14 was in part predicted by refraction at age 6.

Sato (1957) proposes that the mechanism by which near work causes myopia is through accommodation—i.e., the contraction of the ciliary muscle during reading leading to an organic change in, and increased refractive power of, the crystalline lens. Such a mechanism has been used by some authors to account for reports suggesting that the use of negative lenses for the correction of myopia leads to progression (Angle and Wissmann, 1980b; Sato, 1957) and the use of reading lenses leads to regression (Rasmussen, 1954).

A related theory of myopia etiology was proposed by Young (1967), who, citing studies on primates, suggested that myopia may result from near environmental conditions. According to these studies, animals raised in laboratories developed more myopia than animals raised in open field situations. Young also proposed accommodation as the mechanism through which these changes occur, citing studies in which accommodation was immobilized and increases in myopia did not occur. Increase in myopia among submariners, if confirmed, would also be consistent with what might be termed a "close environment" theory.

Psychological Stress

Van Alphen (1961, 1967) theorized that emmetropization proceeds through a feedback process involving the effect of parasympathetic activity on ciliary muscle tonus, which in turn limits the stretch of the sclera by counteracting the effect on the sclera of the intraocular pressure. Specifically, normal emmetropization of the initially hyperopic eye proceeds by a release of parasympathetic tone by higher centers, leading to a decrease in tone in the ciliary muscles, allowing the eye to expand until the emmetropic state is reached and then maintaining it through feedback between the macula and ciliary muscles. The association of myopia with schoolwork, he suggested, is due not to accommodation but to psychological and stress factors interfering with the normal emmetropization mechanism. Van Alphen cited studies showing personality and psychological differences between myopes and nonmyopes to support this hypothesis.

Nutrition

In his study in Tanganyika, McLaren (1960) found that the Mvumi schoolchildren, who had experienced a period of famine, had a similar mean refraction to the Mwanza children, who had not, but they differed from them in showing a greater scatter, more

high ametropias, and more astigmatism and anisometropia. Baldwin (1981) cites studies associated with general malnutrition but notes that no studies to date have shown any relationship between myopia and any specific vitamin deficiency.

Dietary changes have also been suggested as one possible explanation for the increase in myopia observed among Eskimos and American Indians.

Other Causes

The above discussion touches on some of the hypotheses regarding the etiology of the preponderance of myopia as suggested by the prevalence studies that have been reviewed. There are, of course, many special etiologic forms of myopia. Fairly common among these are the myopias seen associated with diabetes and with prematurity. Myopia associated with malnutrition in the sense of deficiency should probably be considered in this category, as well as the myopias associated with specific genetic diseases and with other eye problems leading to a reduction in visual acuity. In populations with a high prevalence of myopia, these special etiologies probably account for a small proportion of myopes, for example, among diabetics and among premature infants, less than one-third of the observed myopia was attributable to diabetes or prematurity (Fledelius, 1980, 1983). Other special etiologies may have a stronger association but are even more rare in the general population. It is not clear what the contribution of these special types is in populations with low myopia prevalence when all factors may be very different.

Appendix E
Glossary

Accommodation (of the eye). Changes in the ciliary muscle and the lens in bringing light rays from various distances to focus upon the retina.

Against-the-rule astigmatism. Astigmatism in which the meridian of greatest refractive power of the eye is the vertical, or 30° either side of vertical. As a consequence, the most minus (or least plus) correction is at, or within, 30° of the vertical.

Ametropia. The refractive condition in which, with accommodation relaxed, parallel rays do not focus on the retina; a condition representing the manifestation of a refractive error.

Amplitude of accommodation. The maximum dioptric lens power increase resulting from contraction of the ciliary muscle in response to a near stimulus.

Anisometropia. A condition of unequal refractive state for the two eyes, one eye requiring a different lens correction from the other.

Astigmatism. A condition of refraction in which rays emanating from a single luminous point are not focused at a single point by an optical system, but instead are focused as a line. In the eye, astigmatism is a refractive anomaly in which incident light is refracted unequally along different meridians. In so-called regular astigmatism, corrected with spectacles, the maximum difference in refraction occurs for meridians 90 degrees apart.

Asthenopia. A general term used to encompass any subjective symptoms of discomfort or eyestrain arising from use of the eyes.

Axial elongation. A lengthening along an axis. In myopia axial elongation refers to a lengthening of the anteroposterior axis of the globe.

Bifocal lenses. A pair of lenses for spectacles or contact lenses, each one having a part that corrects for distant vision and another that corrects for close vision.

Ciliary muscle. The smooth muscle of the ciliary body, involved in ocular accommodation.

Ciliary tonus. Refers to the degree of contraction present in the ciliary muscles when not undergoing active contraction in response to a stimulus.

Contact lens. A lens consisting of a plastic shell which is placed on the cornea for the correction of refractive errors.

Cornea. The transparent most anterior tissue portion of the eyeball.

Cornea curvature. Refers to the degree of curving of the corneal surface.

Crystalline lens. The lens of the eye, a refractive organ of accommodation. A biconvex, transparent, elastic body lying in its capsule immediately behind the pupil of the eye, suspended from the ciliary body by the ciliary zonule.

Cycloplegia. Paralysis of the ciliary muscles of the eyes, which greatly reduces the amplitude of accommodation. Atropine cyclopegia, for example, refers to artificially induced paralysis caused by the anticholinergic agent atropine. Atropine is an example of a cycloplegic drug.

Diopter. A unit of measurement of the refractive power of an optic lens. It is the refractive power of a lens having a focal distance of one meter. Abbreviated: d. or D.

Emmetropia. The absence of refractive error. The condition in which parallel rays are focused exactly on the retina without effort of accommodation.

Esophoria. The convergent position of the eyes with respect to the object of regard when binocular vision is obviated.

Far point of accommodation. The conjugate focus of the retina (fovea) when the accommodation is relaxed or at its minimum. In emmetropia, the far point is said to be infinity; in myopia, it is at some finite distance in front of the eye; in hyperopia, it is at some finite (virtual) distance behind the eye.

Hyperopia. A refractive error in which the focus of parallel rays of light falls behind the retina; due typically to an abnormally short anteroposterior diameter of the eye or to subnormal refractive power. Farsightedness. People with this condition are referred to as hyperopes.

Hypermetropia. Used synonomously with hyperopia.

Hysteresis effect. In the absence of accommodative demand, the tendency of ciliary muscle to maintain a degree of muscle tonus appropriate to focus on a previously presented target.

Incidence. Incidence rate is the number of cases of a disease appearing per unit of population within a defined time interval (typically one year).

Keratometer. An instrument for measuring the curvature of the cornea by utilizing measurments of reflected images formed by the anterior surface of the cornea.

Meridian. The angular orientation on a circle.

Myopia. An optical defect, usually due to too great length of the anteroposterior diameter of the globe, whereby the focal image is formed in front of the retina. Nearsightedness. People with this condition are referred to as myopes.

Myopia progression. The advancement in the severity of myopia with time.

Near point of accommodation. The nearest point on which the eye can focus with maximum accommodation.

Phakometry. Measurement of the crystalline lens power, especially accommodative changes.

Presbyopia. The diminished power of accommodation commonly manifest for near work after the middle forties. It arises from impaired elasticity of the crystalline lens, which

begins in childhood, whereby the near point of distinct vision is removed farther from the eye so that the individual has difficulties in focusing on near objects and in reading fine print.

Prevalence. Proportion of individuals having a specified condition or characteristic at a given time.

Pseudomyopia. The appearance of myopia due to incomplete relaxation of the accommodative mechanism or a spasm of the ciliary muscle.

Refraction. The change in curvature of a wave front which is manifest by the deviation of a ray of light from a straight line in passing obliquely from one transparent medium to another of different density. Also used to refer to the state of refractive power correction needed by the eye. Also, the act of determining the refractive error.

Refractive error. A defect of the eye which prevents parallel light rays from a distinct object from being brought to a single focus precisely on the retina without any accommodation. Usually expressed in terms of the reciprocal in meters of the far point of accommodation.

Retinoscopy. A method of determining the refractive error of the eye by observation of the movement of the shadow phenomena produced and observed by means of a retinoscope. Also referred to as skiascopy.

Senile myopia. Myopia developing in the eye of older people.

Sperical equivalent power. The spherical power equivalent to the power referenced on the circle of least confusion of a spherocyclindrical lens.

Spherical lens. Also referred to as sphere. A lens in which the curved surfaces are segments of a sphere. A minus sphere has curved surfaces which produce a net refracting power which causes light from a distant object to diverge and is used in the optical correction of myopia.

Subjective refraction. Strictly speaking, refers to refraction based on the subject's report but in practice has been broadened to include any determination of refractive error without the use of cyclopegia. Sometimes described as "accommodation relaxed physiologically." The most common procedure is known as "maximum plus to best visual acuity" method.

Visual acuity. The measured central vision for recognition of the smallest spatial separation of objects or parts of an object (e.g., a letter) which can be seen. Dependent upon the clarity of the retinal focus, integrity of the nervous elements, and cerebral interpretation of a given stimulus at a given distance as tested with a Snellen or similar chart. In the USA using Snellen's letter chart at 20 feet, normal visual acuity is at least 20/20 for letters of high contrast with their background.

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